

Chapter N

Characteristics of particular sources and loads

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1 Protection of a LV generator set and the downstream circuits

Most industrial and large commercial electrical installations include certain important loads for which a power supply must be maintained, in the event that the utility electrical supply fails:

- Either, because safety systems are involved (emergency lighting, automatic fire-protection equipment, smoke dispersal fans, alarms and signalization, and so on...) or
- Because it concerns priority circuits, such as certain equipment, the stoppage of which would entail a loss of production, or the destruction of a machine tool, etc.

One of the current means of maintaining a supply to the so-called “priority” loads, in the event that other sources fail, is to install a diesel generator set connected, via a change-over switch, to an emergency-power standby switchboard, from which the priority services are fed (see **Fig. N1**).

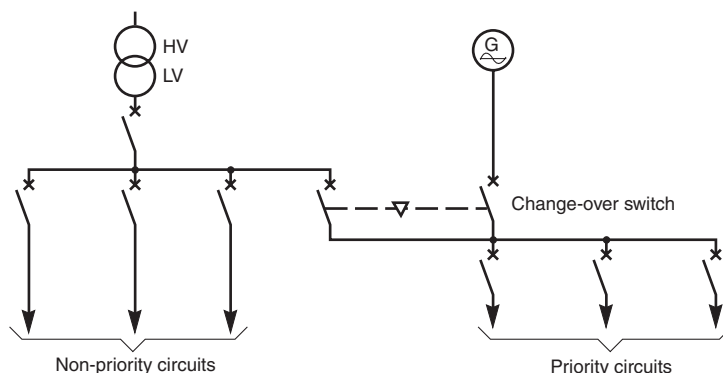


Fig N1 : Example of circuits supplied from a transformer or from an alternator

1.1 Generator protection

Figure N2 below shows the electrical sizing parameters of a Generator Set. P_n , U_n and I_n are, respectively, the power of the thermal motor, the rated voltage and the rated current of the generator.

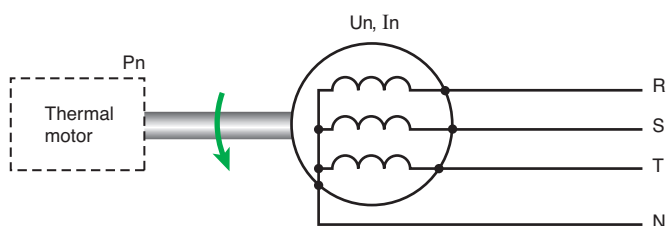


Fig N2 : Block diagram of a generator set

Overload protection

The generator protection curve must be analysed (see **Fig. N3**). Standards and requirements of applications can also stipulate specific overload conditions. For example:

I/I_n	t
1.1	> 1 h
1.5	30 s

The setting possibilities of the overload protection devices (or Long Time Delay) will closely follow these requirements.

Note on overloads

- For economic reasons, the thermal motor of a replacement set may be strictly sized for its nominal power. If there is an active power overload, the diesel motor will stall. The active power balance of the priority loads must take this into account
- A production set must be able to withstand operating overloads:
 - One hour overload
 - One hour 10% overload every 12 hours (Prime Power)

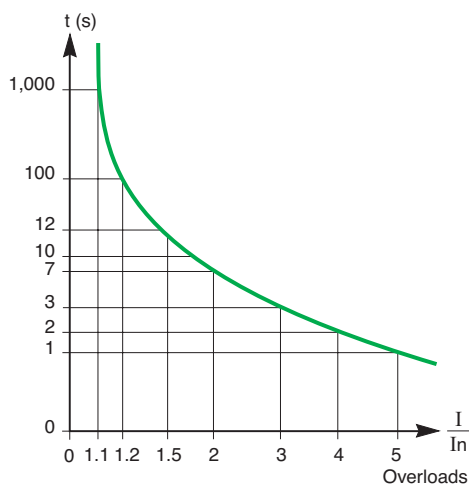


Fig N3 : Example of an overload curve $t = f(I/I_n)$

1 Protection of a LV generator set and the downstream circuits

Short-circuit current protection

Making the short-circuit current

The short-circuit current is the sum:

- Of an aperiodic current
- Of a damped sinusoidal current

The short-circuit current equation shows that it is composed of three successive phases (see **Fig. N4**).

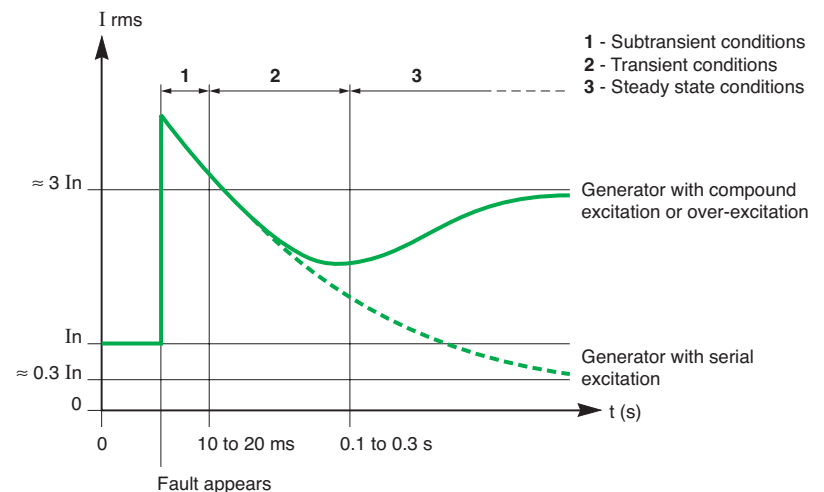


Fig N4 : Short-circuit current level during the 3 phases

■ Subtransient phase

When a short-circuit appears at the terminals of a generator, the current is first made at a relatively high value of around 6 to 12 I_n during the first cycle (0 to 20 ms).

The amplitude of the short-circuit output current is defined by three parameters:

- The subtransient reactance of the generator
- The level of excitation prior to the time of the fault and
- The impedance of the faulty circuit.

The short-circuit impedance of the generator to be considered is the subtransient reactance x''_d expressed in % by the manufacturer. The typical value is 10 to 15%. We determine the subtransient short-circuit impedance of the generator:

$$X''_d(\text{ohms}) = \frac{U_n^2 x''_d}{100 S} \text{ where } S = \sqrt{3} U_n I_n$$

■ Transient phase

The transient phase is placed 100 to 500 ms after the time of the fault. Starting from the value of the fault current of the subtransient period, the current drops to 1.5 to 2 times the current I_n .

The short-circuit impedance to be considered for this period is the transient reactance x'_d expressed in % by the manufacturer. The typical value is 20 to 30%.

■ Steady state phase

The steady state occurs after 500 ms.

When the fault persists, the output voltage collapses and the exciter regulation seeks to raise this output voltage. The result is a stabilised sustained short-circuit current:

- If generator excitation does not increase during a short-circuit (no field overexcitation) but is maintained at the level preceding the fault, the current stabilises at a value that is given by the synchronous reactance X_d of the generator. The typical value of x_d is greater than 200%. Consequently, the final current will be less than the full-load current of the generator, normally around 0.5 I_n .
- If the generator is equipped with maximum field excitation (field overriding) or with compound excitation, the excitation "surge" voltage will cause the fault current to increase for 10 seconds, normally to 2 to 3 times the full-load current of the generator.

1 Protection of a LV generator set and the downstream circuits

Calculating the short-circuit current

Manufacturers normally specify the impedance values and time constants required for analysis of operation in transient or steady state conditions (see **Fig. N5**).

(kVA)	75	200	400	800	1,600	2,500
x''d	10.5	10.4	12.9	10.5	18.8	19.1
x'd	21	15.6	19.4	18	33.8	30.2
xd	280	291	358	280	404	292

Fig N5 : Example of impedance table (in %)

Resistances are always negligible compared with reactances. The parameters for the short-circuit current study are:

■ Value of the short-circuit current at generator terminals

Short-circuit current amplitude in transient conditions is:

$$I_{sc3} = \frac{I_n}{X'd} \frac{1}{\sqrt{3}} \quad (X'd \text{ in ohms})$$

or

$$I_{sc3} = \frac{I_n}{x'd} 100 \quad (x'd \text{ in \%})$$

I_n is the generator phase-to-phase output voltage.

Note: This value can be compared with the short-circuit current at the terminals of a transformer. Thus, for the same power, currents in event of a short-circuit close to a generator will be 5 to 6 times weaker than those that may occur with a transformer (main source).

This difference is accentuated still further by the fact that generator set power is normally less than that of the transformer (see **Fig. N6**).

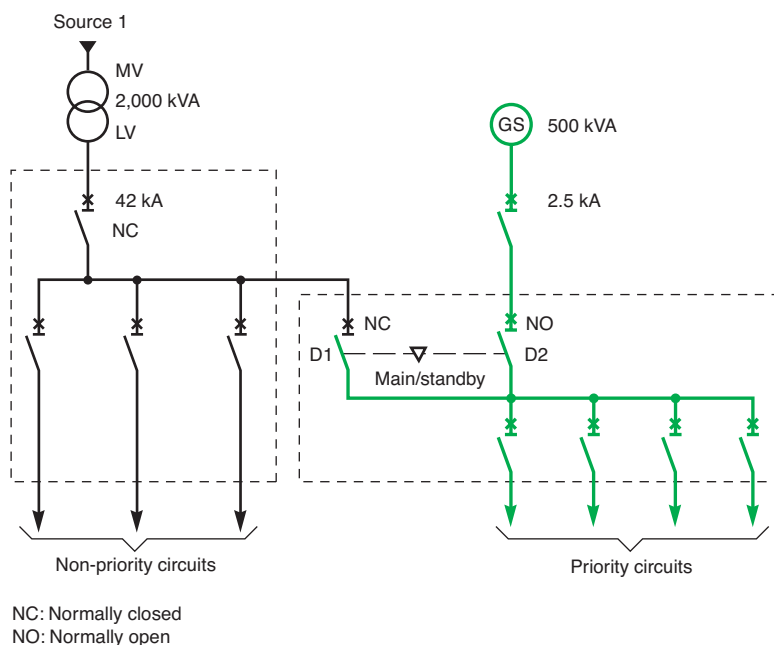


Fig N6 : Example of a priority services switchboard supplied (in an emergency) from a standby generator set

When the LV network is supplied by the Main source 1 of 2,000 kVA, the short-circuit current is 42 kA at the main LV board busbar. When the LV network is supplied by the Replacement Source 2 of 500 kVA with transient reactance of 30%, the short-circuit current is made at approx. 2.5 kA, i.e. at a value 16 times weaker than with the Main source.

1 Protection of a LV generator set and the downstream circuits

1.2 Downstream LV network protection

Priority circuit protection

Choice of breaking capacity

This must be systematically checked with the characteristics of the main source (MV/LV transformer).

Setting of the Short Time Delay (STD) tripping current

■ Subdistribution boards

The ratings of the protection devices for the subdistribution and final distribution circuits are always lower than the generator rated current. Consequently, except in special cases, conditions are the same as with transformer supply.

■ Main LV switchboard

□ The sizing of the main feeder protection devices is normally similar to that of the generator set. Setting of the STD must allow for the short-circuit characteristic of the generator set (see "Short-circuit current protection" before)

□ Discrimination of protection devices on the priority feeders must be provided in generator set operation (it can even be compulsory for safety feeders). It is necessary to check proper staggering of STD setting of the protection devices of the main feeders with that of the subdistribution protection devices downstream (normally set for distribution circuits at 10 In).

Note: When operating on the generator set, use of a low sensitivity Residual Current Device enables management of the insulation fault and ensures very simple discrimination.

Safety of people

In the IT (2nd fault) and TN grounding systems, protection of people against indirect contacts is provided by the STD protection of circuit-breakers. Their operation on a fault must be ensured, whether the installation is supplied by the main source (Transformer) or by the replacement source (generator set).

Calculating the insulation fault current

Zero-sequence reactance formulated as a% of U₀ by the manufacturer x'o.

The typical value is 8%.

The phase-to-neutral single-phase short-circuit current is given by:

$$I_f = \frac{U_n \sqrt{3}}{2 X'd + X'o}$$

The insulation fault current in the TN system is slightly greater than the three phase fault current. For example, in event of an insulation fault on the system in the previous example, the insulation fault current is equal to 3 kA.

1.3 The monitoring functions

Due to the specific characteristics of the generator and its regulation, the proper operating parameters of the generator set must be monitored when special loads are implemented.

The behaviour of the generator is different from that of the transformer:

- The active power it supplies is optimised for a power factor = 0.8
- At less than power factor 0.8, the generator may, by increased excitation, supply part of the reactive power

Capacitor bank

An off-load generator connected to a capacitor bank may self-excite, consequently increasing its overvoltage.

The capacitor banks used for power factor regulation must therefore be disconnected. This operation can be performed by sending the stopping setpoint to the regulator (if it is connected to the system managing the source switchings) or by opening the circuit-breaker supplying the capacitors.

If capacitors continue to be necessary, do not use regulation of the power factor relay in this case (incorrect and over-slow setting).

Motor restart and re-acceleration

A generator can supply at most in transient period a current of between 3 and 5 times its nominal current.

A motor absorbs roughly 6 In for 2 to 20 s during start-up.

1 Protection of a LV generator set and the downstream circuits

If the sum of the motor power is high, simultaneous start-up of loads generates a high pick-up current that can be damaging. A large voltage drop, due to the high value of the generator transient and subtransient reactances will occur (20% to 30%), with a risk of:

- Non-starting of motors
- Temperature rise linked to the prolonged starting time due to the voltage drop
- Tripping of the thermal protection devices

Moreover, all the network and actuators are disturbed by the voltage drop.

Application (see Fig. N7)

A generator supplies a set of motors.

Generator characteristics: $P_n = 130$ kVA at a power factor of 0.8,

$I_n = 150$ A

$x'd = 20\%$ (for example) hence $I_{sc} = 750$ A.

- The ΣP_{motors} is 45 kW (45% of generator power)

Calculating voltage drop at start-up:

$\Sigma P_{Motors} = 45$ kW, $I_m = 81$ A, hence a starting current $I_d = 480$ A for 2 to 20 s.

Voltage drop on the busbar for simultaneous motor starting:

$$\frac{\Delta U}{U} = \left(\frac{I_d - I_n}{I_{sc} - I_n} \right) \text{ in } \%$$

$$\Delta U = 55\%$$

which is not tolerable for motors (failure to start).

- the ΣP_{motors} is 20 kW (20% of generator power)

Calculating voltage drop at start-up:

$\Sigma P_{Motors} = 20$ kW, $I_m = 35$ A, hence a starting current $I_d = 210$ A for 2 to 20 s.

Voltage drop on the busbar:

$$\frac{\Delta U}{U} = \left(\frac{I_d - I_n}{I_{sc} - I_n} \right) \text{ in } \%$$

$$\Delta U = 10\%$$

which is high but tolerable (depending on the type of loads).

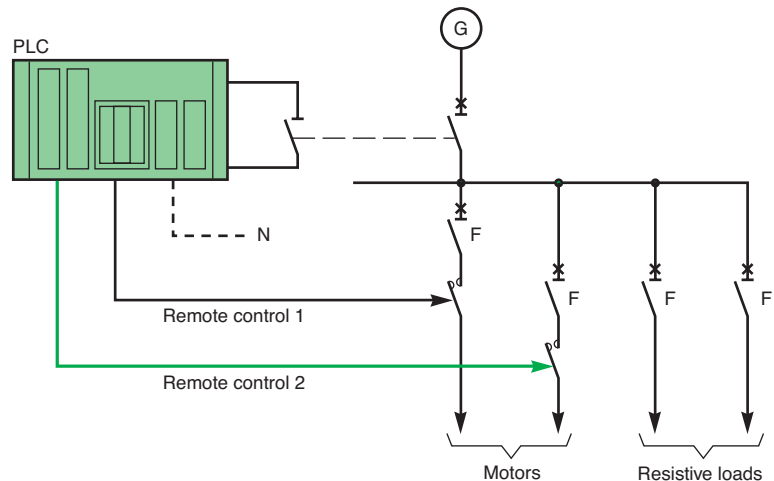


Fig N7 : Restarting of priority motors ($\Sigma P > 1/3 P_n$)

Restarting tips

- If the P_{max} of the largest motor $> \frac{1}{3} P_n$, a soft starter must be installed on this motor

- If $\Sigma P_{motors} > \frac{1}{3} P_n$, motor cascade restarting must be managed by a PLC

- If $\Sigma P_{motors} < \frac{1}{3} P_n$, there are no restarting problems

1 Protection of a LV generator set and the downstream circuits

Non-linear loads – Example of a UPS

Non-linear loads

These are mainly:

- Saturated magnetic circuits
- Discharge lamps, fluorescent lights
- Electronic converters
- Information Technology Equipment: PC, computers, etc.

These loads generate harmonic currents: supplied by a Generator Set, this can create high voltage distortion due to the low short-circuit power of the generator.

Uninterruptible Power Supply (UPS) (see Fig. N8)

The combination of a UPS and generator set is the best solution for ensuring quality power supply with long autonomy for the supply of sensitive loads.

It is also a non-linear load due to the input rectifier. On source switching, the autonomy of the UPS on battery must allow starting and connection of the Generator Set.

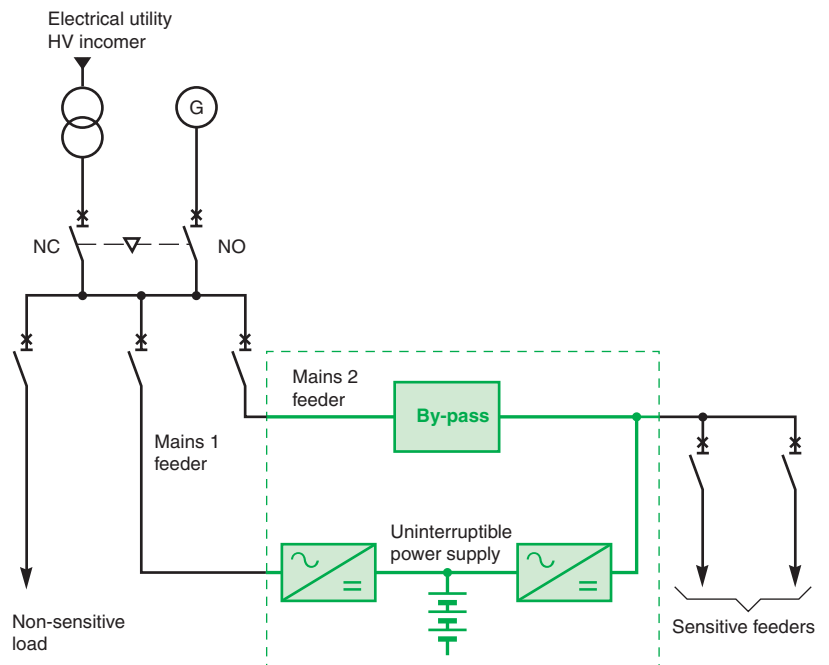


Fig N8 : Generator set- UPS combination for Quality energy

UPS power

UPS inrush power must allow for:

- Nominal power of the downstream loads. This is the sum of the apparent powers P_a absorbed by each application. Furthermore, so as not to oversize the installation, the overload capacities at UPS level must be considered (for example: 1.5 I_n for 1 minute and 1.25 I_n for 10 minutes)
- The power required to recharge the battery: This current is proportional to the autonomy required for a given power. The sizing S_r of a UPS is given by:

$$S_r = 1.17 \times P_n$$

Figure N9 next page defines the pick-up currents and protection devices for supplying the rectifier (Mains 1) and the standby mains (Mains 2).

1 Protection of a LV generator set and the downstream circuits

Nominal power Pn (kVA)	Current value (A) Mains 1 with 3Ph battery 400 V - I1	Mains 2 or 3Ph application 400 V - Iu
40	86	60.5
60	123	91
80	158	121
100	198	151
120	240	182
160	317	243
200	395	304
250	493	360
300	590	456
400	793	608
500	990	760
600	1,180	912
800	1,648	1,215

Fig N9 : Pick-up current for supplying the rectifier and standby mains

Generator Set/UPS combination

■ Restarting the Rectifier on a Generator Set

The UPS rectifier can be equipped with a progressive starting of the charger to prevent harmful pick-up currents when installation supply switches to the Generator Set (see **Fig. N10**).

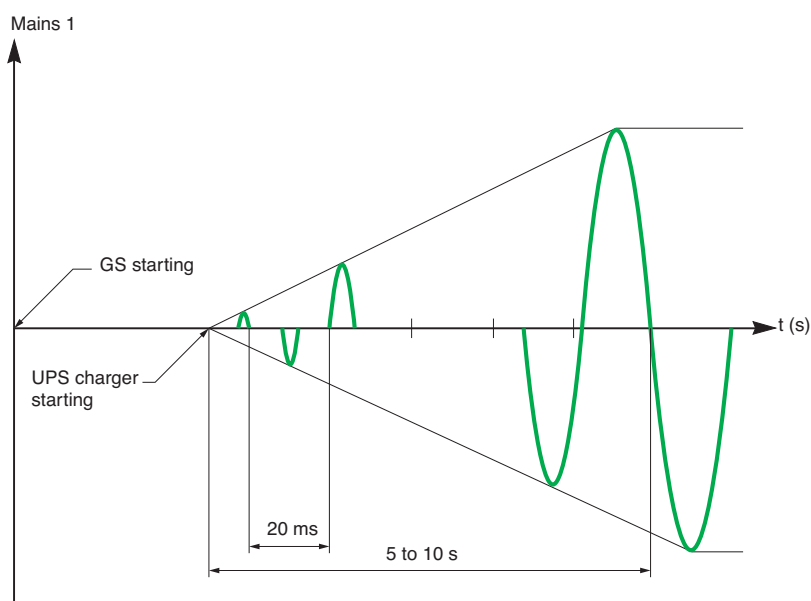


Fig N10 : Progressive starting of a type 2 UPS rectifier

■ Harmonics and voltage distortion

Total voltage distortion τ is defined by:

$$\tau(\%) = \frac{\sqrt{\sum U_h^2}}{U_1}$$

where U_h is the harmonic voltage of order h .

This value depends on:

- The harmonic currents generated by the rectifier (proportional to the power S_r of the rectifier)
- The longitudinal subtransient reactance X''_d of the generator
- The power S_g of the generator

We define $U'R_{cc}(\%) = X''_d \frac{S_r}{S_g}$ the generator relative short-circuit voltage, brought to rectifier power, i.e. $t = f(U'R_{cc})$.

1 Protection of a LV generator set and the downstream circuits

Note 1: As subtransient reactance is great, harmonic distortion is normally too high compared with the tolerated value (7 to 8%) for reasonable economic sizing of the generator: use of a suitable filter is an appropriate and cost-effective solution.

Note 2: Harmonic distortion is not harmful for the rectifier but may be harmful for the other loads supplied in parallel with the rectifier.

Application

A chart is used to find the distortion τ as a function of $U'R_{cc}$ (see **Fig. N11**).

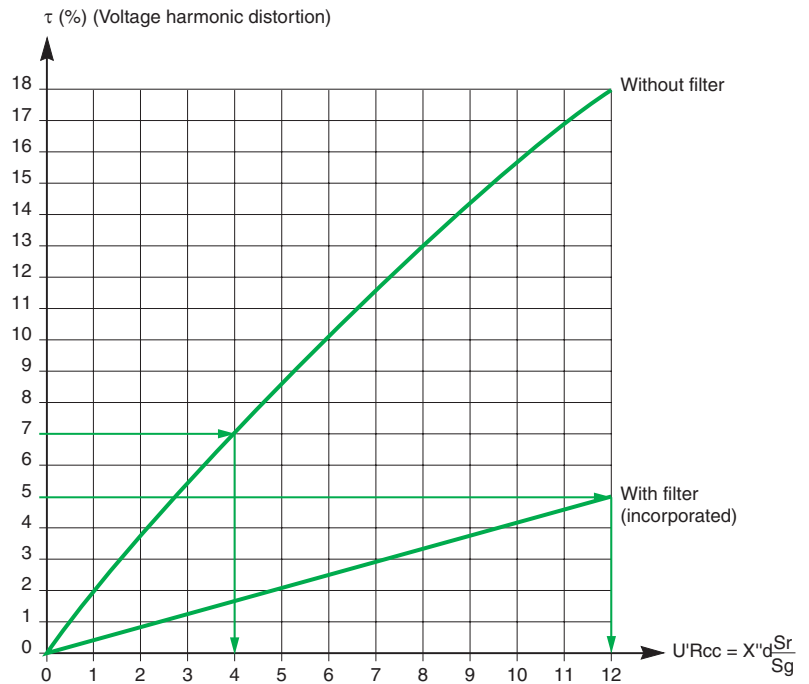


Fig N11 : Chart for calculating harmonic distortion

The chart gives:

- Either τ as a function of $U'R_{cc}$
- Or $U'R_{cc}$ as a function of τ

From which generator set sizing, S_g , is determined.

Example: Generator sizing

- 300 kVA UPS without filter, subtransient reactance of 15%

The power S_r of the rectifier is $S_r = 1.17 \times 300 \text{ kVA} = 351 \text{ kVA}$

For a $\tau < 7\%$, the chart gives $U'R_{cc} = 4\%$, power S_g is:

$$S_g = 351 \times \frac{15}{4} \approx 1,400 \text{ kVA}$$

- 300 kVA UPS with filter, subtransient reactance of 15%

For $\tau = 5\%$, the calculation gives $U'R_{cc} = 12\%$, power S_g is:

$$S_g = 351 \times \frac{15}{12} \approx 500 \text{ kVA}$$

Note: With an upstream transformer of 630 kVA on the 300 kVA UPS without filter, the 5% ratio would be obtained.

The result is that operation on generator set must be continually monitored for harmonic currents.

If voltage harmonic distortion is too great, use of a filter on the network is the most effective solution to bring it back to values that can be tolerated by sensitive loads.

1 Protection of a LV generator set and the downstream circuits

1.4 Generator Set parallel-connection

Parallel-connection of the generator set irrespective of the application type - Safety source, Replacement source or Production source - requires finer management of connection, i.e. additional monitoring functions.

Parallel operation

As generator sets generate energy in parallel on the same load, they must be synchronised properly (voltage, frequency) and load distribution must be balanced properly. This function is performed by the regulator of each Generator Set (thermal and excitation regulation). The parameters (frequency, voltage) are monitored before connection: if the values of these parameters are correct, connection can take place.

Insulation faults (see Fig. N12)

An insulation fault inside the metal casing of a generator set may seriously damage the generator of this set if the latter resembles a phase-to-neutral short-circuit. The fault must be detected and eliminated quickly, else the other generators will generate energy in the fault and trip on overload: installation continuity of supply will no longer be guaranteed. Ground Fault Protection (GFP) built into the generator circuit is used to:

- Quickly disconnect the faulty generator and preserve continuity of supply
- Act at the faulty generator control circuits to stop it and reduce the risk of damage

This GFP is of the "Residual Sensing" type and must be installed as close as possible to the protection device as per a TN-C/TN-S⁽¹⁾ system at each generator set with grounding of frames by a separate PE. This kind of protection is usually called "Restricted Earth Fault".

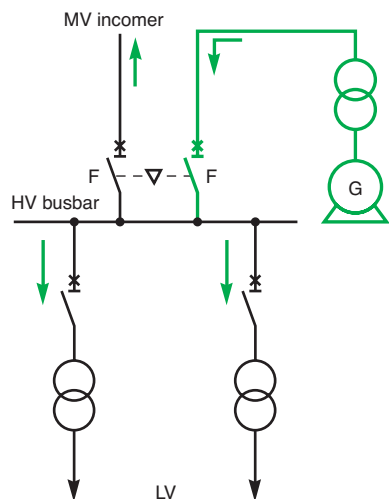


Fig N13 : Energy transfer direction – Generator Set as a generator

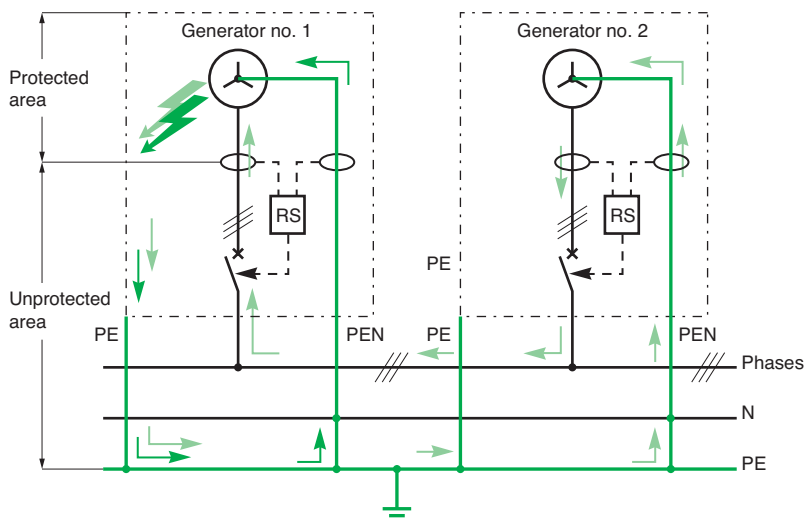


Fig N12 : Insulation fault inside a generator

Generator Set operating as a load (see Fig. N13 and Fig. N14)

One of the parallel-connected generator sets may no longer operate as a generator but as a motor (by loss of its excitation for example). This may generate overloading of the other generator set(s) and thus place the electrical installation out of operation.

To check that the generator set really is supplying the installation with power (operation as a generator), the proper flow direction of energy on the coupling busbar must be checked using a specific "reverse power" check. Should a fault occur, i.e. the set operates as a motor, this function will eliminate the faulty set.

Grounding parallel-connected Generator Sets

Grounding of connected generator sets may lead to circulation of earth fault currents (triplen harmonics) by connection of neutrals for common grounding (grounding system of the TN or TT type). Consequently, to prevent these currents from flowing between the generator sets, we recommend the installation of a decoupling resistance in the grounding circuit.

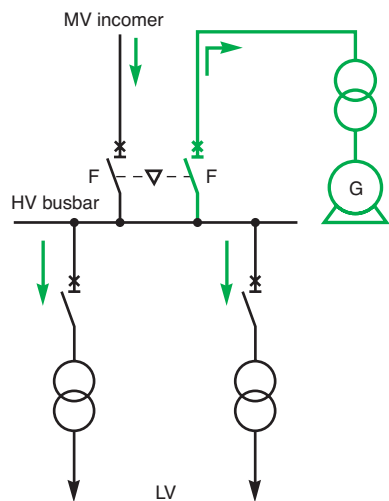


Fig N14 : Energy transfer direction – Generator Set as a load

(1) The system is in TN-C for sets seen as the "generator" and in TN-S for sets seen as "loads"

2 Uninterruptible Power Supply units (UPS)

2.1 Availability and quality of electrical power

The disturbances presented above may affect:

- Safety of human life
- Safety of property
- The economic viability of a company or production process

Disturbances must therefore be eliminated.

A number of technical solutions contribute to this goal, with varying degrees of effectiveness. These solutions may be compared on the basis of two criteria:

- Availability of the power supplied
- Quality of the power supplied

The availability of electrical power can be thought of as the time per year that power is present at the load terminals. Availability is mainly affected by power interruptions due to utility outages or electrical faults.

A number of solutions exist to limit the risk:

- Division of the installation so as to use a number of different sources rather than just one
- Subdivision of the installation into priority and non-priority circuits, where the supply of power to priority circuits can be picked up if necessary by another available source
- Load shedding, as required, so that a reduced available power rating can be used to supply standby power
- Selection of a system earthing arrangement suited to service-continuity goals, e.g. IT system
- Discrimination of protection devices (selective tripping) to limit the consequences of a fault to a part of the installation

Note that the only way of ensuring availability of power with respect to utility outages is to provide, in addition to the above measures, an autonomous alternate source, at least for priority loads (see **Fig. N15**).

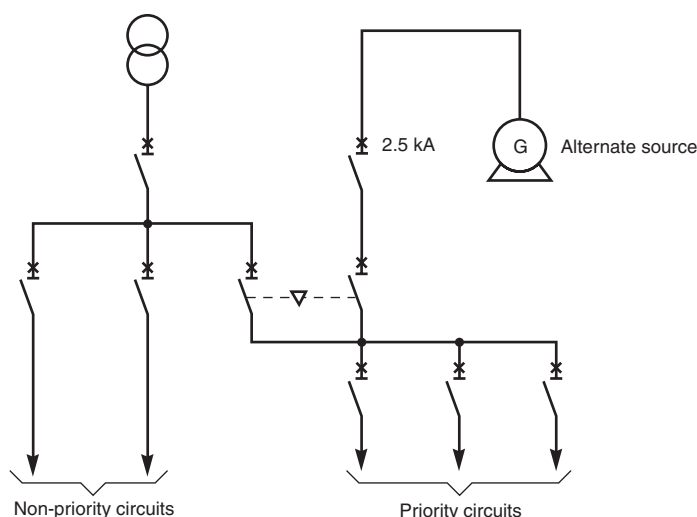


Fig. N15 : Availability of electrical power

This source takes over from the utility in the event of a problem, but two factors must be taken into account:

- The transfer time (time required to take over from the utility) which must be acceptable to the load
- The operating time during which it can supply the load

The quality of electrical power is determined by the elimination of the disturbances at the load terminals.

An alternate source is a means to ensure the availability of power at the load terminals, however, it does not guarantee, in many cases, the quality of the power supplied with respect to the above disturbances.

N11

2 Uninterruptible Power Supply units (UPS)

Today, many sensitive electronic applications require an electrical power supply which is virtually free of these disturbances, to say nothing of outages, with tolerances that are stricter than those of the utility.

This is the case, for example, for computer centers, telephone exchanges and many industrial-process control and monitoring systems.

These applications require solutions that ensure both the availability and quality of electrical power.

The UPS solution

The solution for sensitive applications is to provide a power interface between the utility and the sensitive loads, providing voltage that is:

- Free of all disturbances present in utility power and in compliance with the strict tolerances required by loads

- Available in the event of a utility outage, within specified tolerances

UPSs (Uninterruptible Power Supplies) satisfy these requirements in terms of power availability and quality by:

- Supplying loads with voltage complying with strict tolerances, through use of an inverter

- Providing an autonomous alternate source, through use of a battery

- Stepping in to replace utility power with no transfer time, i.e. without any interruption in the supply of power to the load, through use of a static switch

These characteristics make UPSs the ideal power supply for all sensitive applications because they ensure power quality and availability, whatever the state of utility power.

A UPS comprises the following main components:

- Rectifier/charger, which produces DC power to charge a battery and supply an inverter

- Inverter, which produces quality electrical power, i.e.

- Free of all utility-power disturbances, notably micro-outages

- Within tolerances compatible with the requirements of sensitive electronic devices (e.g. for Galaxy, tolerances in amplitude $\pm 0.5\%$ and frequency $\pm 1\%$, compared to $\pm 10\%$ and $\pm 5\%$ in utility power systems, which correspond to improvement factors of 20 and 5, respectively)

- Battery, which provides sufficient backup time (8 minutes to 1 hour or more) to ensure the safety of life and property by replacing the utility as required

- Static switch, a semi-conductor based device which transfers the load from the inverter to the utility and back, without any interruption in the supply of power

2.2 Types of static UPSs

Types of static UPSs are defined by standard IEC 62040.

The standard distinguishes three operating modes:

- Passive standby (also called off-line)

- Line interactive

- Double conversion (also called on-line)

These definitions concern UPS operation with respect to the power source including the distribution system upstream of the UPS.

Standard IEC 62040 defines the following terms:

- Primary power: power normally continuously available which is usually supplied by an electrical utility company, but sometimes by the user's own generation

- Standby power: power intended to replace the primary power in the event of primary-power failure

- Bypass power: power supplied via the bypass

Practically speaking, a UPS is equipped with two AC inputs, which are called the normal AC input and bypass AC input in this guide.

- The normal AC input, noted as mains input 1, is supplied by the primary power, i.e. by a cable connected to a feeder on the upstream utility or private distribution system

- The bypass AC input, noted as mains input 2, is generally supplied by standby power, i.e. by a cable connected to an upstream feeder other than the one supplying the normal AC input, backed up by an alternate source (e.g. by an engine-generator set or another UPS, etc.)

When standby power is not available, the bypass AC input is supplied with primary power (second cable parallel to the one connected to the normal AC input).

The bypass AC input is used to supply the bypass line(s) of the UPS, if they exist. Consequently, the bypass line(s) is supplied with primary or standby power, depending on the availability of a standby-power source.

UPS operating in passive-standby (off-line) mode

Operating principle

The inverter is connected in parallel with the AC input in a standby (see Fig. N16).

■ Normal mode

The load is supplied by utility power via a filter which eliminates certain disturbances and provides some degree of voltage regulation (the standard speaks of “additional devices...to provide power conditioning”). The inverter operates in passive standby mode.

■ Battery backup mode

When the AC input voltage is outside specified tolerances for the UPS or the utility power fails, the inverter and the battery step in to ensure a continuous supply of power to the load following a very short (<10 ms) transfer time.

The UPS continues to operate on battery power until the end of battery backup time or the utility power returns to normal, which provokes transfer of the load back to the AC input (normal mode).

Usage

This configuration is in fact a compromise between an acceptable level of protection against disturbances and cost. It can be used only with low power ratings (< 2 kVA). It operates without a real static switch, so a certain time is required to transfer the load to the inverter. This time is acceptable for certain individual applications, but incompatible with the performance required by more sophisticated, sensitive systems (large computer centers, telephone exchanges, etc.).

What is more, the frequency is not regulated and there is no bypass.

Note: In normal mode, the power supplying the load does not flow through the inverter, which explains why this type of UPS is sometimes called “Off-line”. This term is misleading, however, because it also suggests “not supplied by utility power”, when in fact the load is supplied by the utility via the AC input during normal operation. That is why standard IEC 62040 recommends the term “passive standby”.

UPS operating in line-interactive mode

Operating principle

The inverter is connected in parallel with the AC input in a standby configuration, but also charges the battery. It thus interacts (reversible operation) with the AC input source (see Fig. N17).

■ Normal mode

The load is supplied with conditioned power via a parallel connection of the AC input and the inverter. The inverter operates to provide output-voltage conditioning and/or charge the battery. The output frequency depends on the AC-input frequency.

■ Battery backup mode

When the AC input voltage is outside specified tolerances for the UPS or the utility power fails, the inverter and the battery step in to ensure a continuous supply of power to the load following a transfer without interruption using a static switch which also disconnects the AC input to prevent power from the inverter from flowing upstream. The UPS continues to operate on battery power until the end of battery backup time or the utility power returns to normal, which provokes transfer of the load back to the AC input (normal mode).

■ Bypass mode

This type of UPS may be equipped with a bypass. If one of the UPS functions fails, the load can be transferred to the bypass AC input (supplied with utility or standby power, depending on the installation).

Usage

This configuration is not well suited to regulation of sensitive loads in the medium to high-power range because frequency regulation is not possible. For this reason, it is rarely used other than for low power ratings.

UPS operating in double-conversion (on-line) mode

Operating principle

The inverter is connected in series between the AC input and the application.

■ Normal mode

During normal operation, all the power supplied to the load passes through the rectifier/charger and inverter which together perform a double conversion (AC-DC-AC), hence the name.

■ Battery backup mode

When the AC input voltage is outside specified tolerances for the UPS or the utility power fails, the inverter and the battery step in to ensure a continuous supply of power to the load following a transfer without interruption using a static switch. The UPS continues to operate on battery power until the end of battery backup time or utility power returns to normal, which provokes transfer of the load back to the AC input (normal mode).

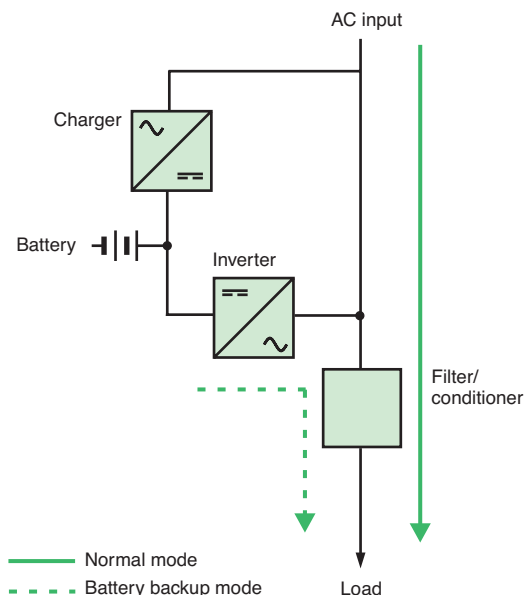


Fig. N16 : UPS operating in passive standby mode

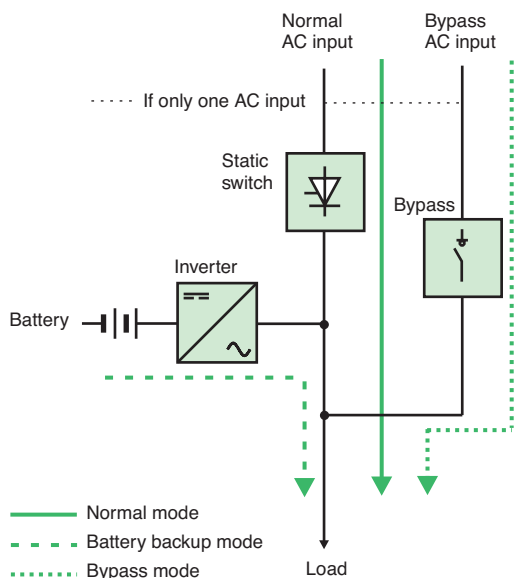


Fig. N17 : UPS operating in line-interactive mode

2 Uninterruptible Power Supply units (UPS)

■ Bypass mode

This type of UPS is generally equipped with a static bypass, sometimes referred to as a static switch (see **Fig. N18**).

The load can be transferred without interruption to the bypass AC input (supplied with utility or standby power, depending on the installation), in the event of the following:

- UPS failure
- Load-current transients (inrush or fault currents)
- Load peaks

However, the presence of a bypass assumes that the input and output frequencies are identical and if the voltage levels are not the same, a bypass transformer is required.

For certain loads, the UPS must be synchronized with the bypass power to ensure load-supply continuity. What is more, when the UPS is in bypass mode, a disturbance on the AC input source may be transmitted directly to the load because the inverter no longer steps in.

Note: Another bypass line, often called the maintenance bypass, is available for maintenance purposes. It is closed by a manual switch.

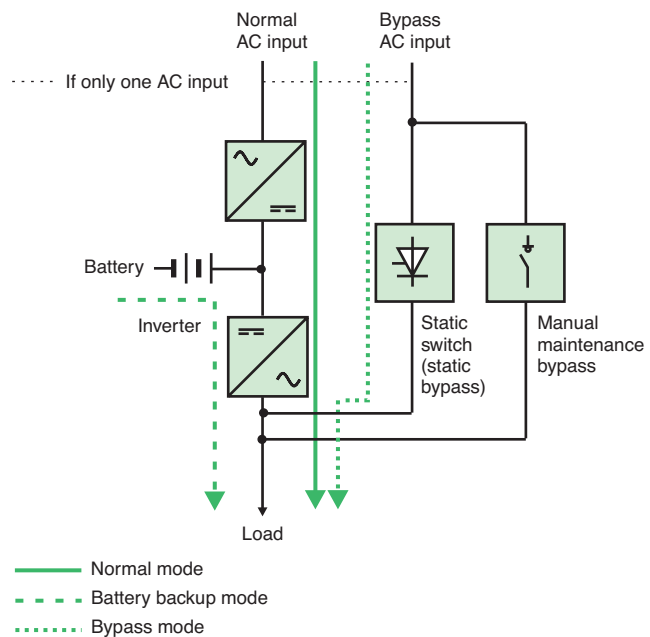


Fig. N18 : UPS operating in double-conversion (on-line) mode

Usage

In this configuration, the time required to transfer the load to the inverter is negligible due to the static switch.

Also, the output voltage and frequency do not depend on the input voltage and frequency conditions. This means that the UPS, when designed for this purpose, can operate as a frequency converter.

Practically speaking, this is the main configuration used for medium and high power ratings (from 10 kVA upwards). The rest of this chapter will consider only this configuration.

Note: This type of UPS is often called “on-line”, meaning that the load is continuously supplied by the inverter, regardless of the conditions on the AC input source. This term is misleading, however, because it also suggests “supplied by utility power”, when in fact the load is supplied by power that has been reconstituted by the double-conversion system. That is why standard IEC 62040 recommends the term “double conversion”.

2.3 Batteries

Selection of battery type

A battery is made up of interconnected cells which may be vented or of the recombination type.

There are two main families of batteries:

- Nickel-cadmium batteries
- Lead-acid batteries
 - Vented cells (lead-antimony): They are equipped with ports to release to the atmosphere the oxygen and hydrogen produced during the different chemical reactions
 - Top off the electrolyte by adding distilled or demineralized water
 - Recombination cells (lead, pure lead, lead-tin batteries): The gas recombination rate is at least 95% and they therefore do not require water to be added during service life

By extension, reference will be made to vented or recombination batteries (recombination batteries are also often called "sealed" batteries).

The main types of batteries used in conjunction with UPSs are:

- Sealed lead-acid batteries, used 95% of the time because they are easy to maintain and do not require a special room
- Vented lead-acid batteries
- Vented nickel-cadmium batteries

The above three types of batteries may be proposed, depending on economic factors and the operating requirements of the installation, with all the available service-life durations.

Capacity levels and backup times may be adapted to suit the user's needs.

The proposed batteries are also perfectly suited to UPS applications in that they are the result of collaboration with leading battery manufacturers.

Selection of back up time

Selection depends on:

- The average duration of power-system failures
- Any available long-lasting standby power (engine-generator set, etc.)
- The type of application

The typical range generally proposed is:

- Standard backup times of 10, 15 or 30 minutes
- Custom backup times

The following general rules apply:

- Computer applications

Battery backup time must be sufficient to cover file-saving and system-shutdown procedures required to ensure a controlled shutdown of the computer system.

Generally speaking, the computer department determines the necessary backup time, depending on its specific requirements.

- Industrial processes

The backup time calculation should take into account the economic cost incurred by an interruption in the process and the time required to restart.

Selection table

Figure N19 next page sums up the main characteristics of the various types of batteries.

Increasingly, recombination batteries would seem to be the market choice for the following reasons:

- No maintenance
- Easy implementation
- Installation in all types of rooms (computer rooms, technical rooms not specifically intended for batteries, etc.)

In certain cases, however, vented batteries are preferred, notably for:

- Long service life
- Long backup times
- High power ratings

Vented batteries must be installed in special rooms complying with precise regulations and require appropriate maintenance.

	Service life	Compact	Operating-temperature tolerances	Frequency of maintenance	Special room	Cost
Sealed lead-acid	5 or 10 years	+	+	Low	No	Low medium
Vented lead-acid	5 or 10 years	+	++	Medium	Yes	Low
Nickel-cadmium	5 or 10 years	++	+++	High	no	High

Fig. N19 : Main characteristics of the various types of batteries

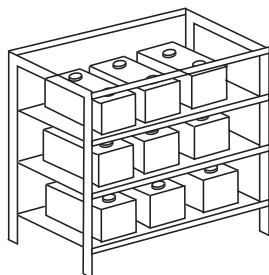


Fig. N20 : Shelf mounting

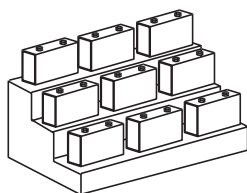


Fig. N21 : Tier mounting

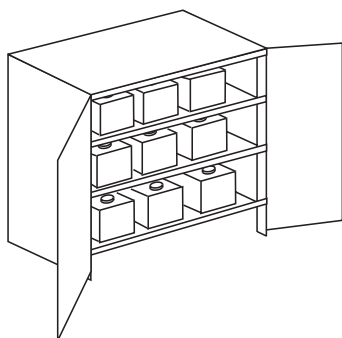


Fig. N22 : Cabinet mounting

Installation methods

Depending on the UPS range, the battery capacity and backup time, the battery is:

- Sealed type and housed in the UPS cabinet
- Sealed type and housed in one to three cabinets
- Vented or sealed type and rack-mounted. In this case the installation method may be
 - On shelves (see Fig. N20)

This installation method is possible for sealed batteries or maintenance-free vented batteries which do not require topping up of their electrolyte.

- Tier mounting (see Fig. N21)

This installation method is suitable for all types of batteries and for vented batteries in particular, as level checking and filling are made easy.

- In cabinets (see Fig. N22)

This installation method is suitable for sealed batteries. It is easy to implement and offers maximum safety.

2.4 System earthing arrangements for installations comprising UPSs

Application of protection systems, stipulated by the standards, in installations comprising a UPS, requires a number of precautions for the following reasons:

- The UPS plays two roles
 - A load for the upstream system
 - A power source for downstream system
- When the battery is not installed in a cabinet, an insulation fault on the DC system can lead to the flow of a residual DC component

This component can disturb the operation of certain protection devices, notably RCDs used for the protection of persons.

Protection against direct contact (see Fig. N23)

All installations satisfy the applicable requirements because the equipment is housed in cabinets providing a degree of protection IP 20. This is true even for the battery when it is housed in a cabinet.

When batteries are not installed in a cabinet, i.e. generally in a special room, the measures presented at the end of this chapter should be implemented.

Note: The TN system (version TN-S or TN-C) is the most commonly recommended system for the supply of computer systems.

N16

Type of arrangement	IT system	TT system	TN system
Operation	■ Signaling of first insulation fault ■ Locating and elimination of first fault ■ Disconnection for second insulation fault	■ Disconnection for first insulation fault	■ Disconnection for first insulation fault
Techniques for protection of persons	■ Interconnection and earthing of conductive parts ■ Surveillance of first fault using an insulation monitoring device (IMD) ■ Second fault results in circuit interruption (circuit-breaker or fuse)	■ Earthing of conductive parts combined with use of RCDs ■ First insulation fault results in interruption by detecting leakage currents	■ Interconnection and earthing of conductive parts and neutral imperative ■ First insulation fault results in interruption by detecting overcurrents (circuit-breaker or fuse)
Advantages and disadvantages	■ Solution offering the best continuity of service (first fault is signalled) ■ Requires competent surveillance personnel (location of first fault)	■ Easiest solution in terms of design and installation ■ No insulation monitoring device (IMD) required ■ However, each fault results in interruption of the concerned circuit	■ Low-cost solution in terms of installation ■ Difficult design (calculation of loop impedances) ■ Qualified operating personnel required ■ Flow of high fault currents

Fig. N23 : Main characteristics of system earthing arrangements

2 Uninterruptible Power Supply units (UPS)

Essential points to be checked for UPSs

Figure N24 shows all the essential points that must be interconnected as well as the devices to be installed (transformers, RCDs, etc.) to ensure installation conformity with safety standards.

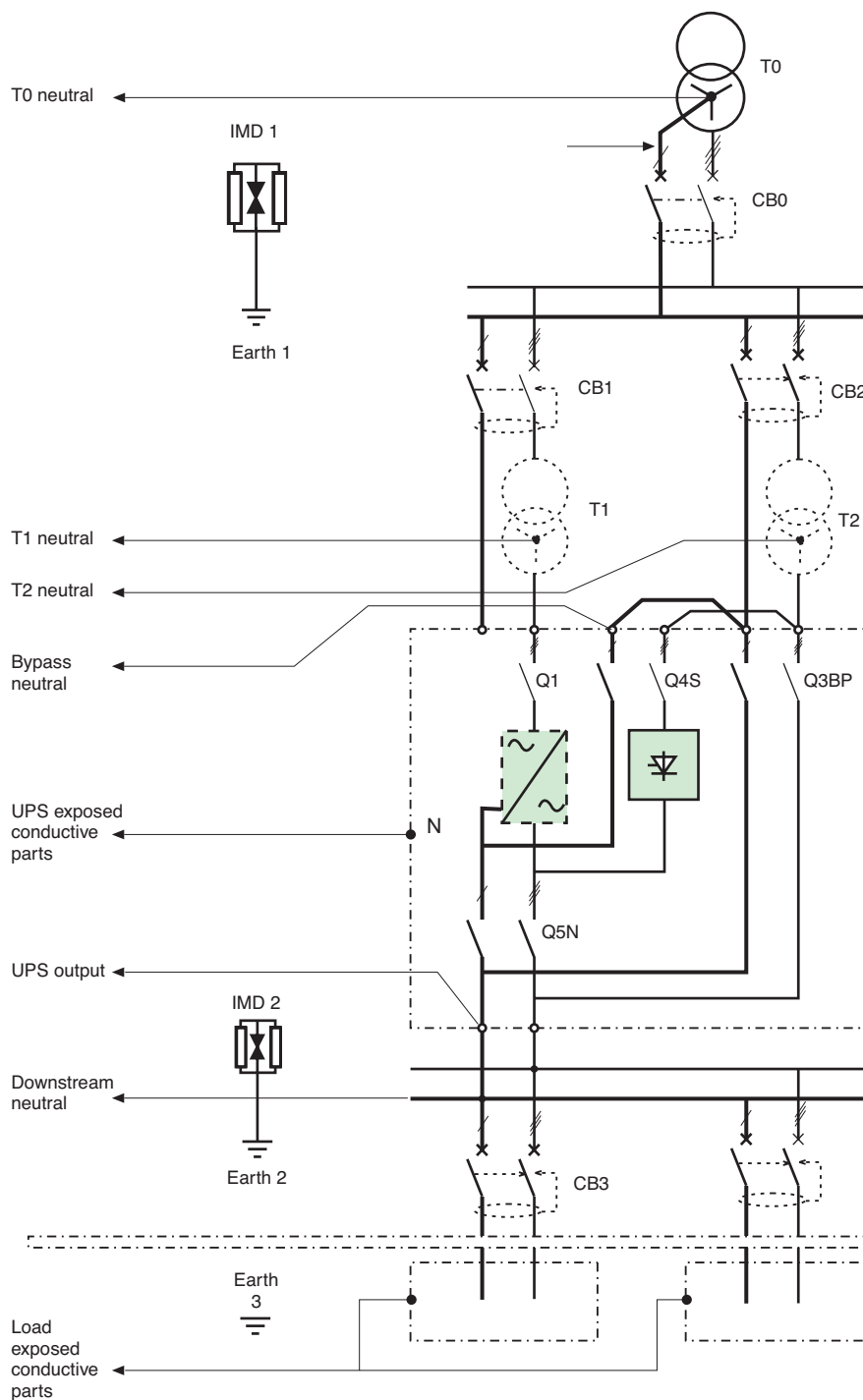


Fig. N24 : The essential points that must be connected in system earthing arrangements

2.5 Choice of protection schemes

The circuit-breakers have a major role in an installation but their importance often appears at the time of accidental events which are not frequent. The best sizing of UPS and the best choice of configuration can be compromised by a wrong choice of only one circuit-breaker.

Circuit-breaker selection

Figure N25 shows how to select the circuit-breakers.

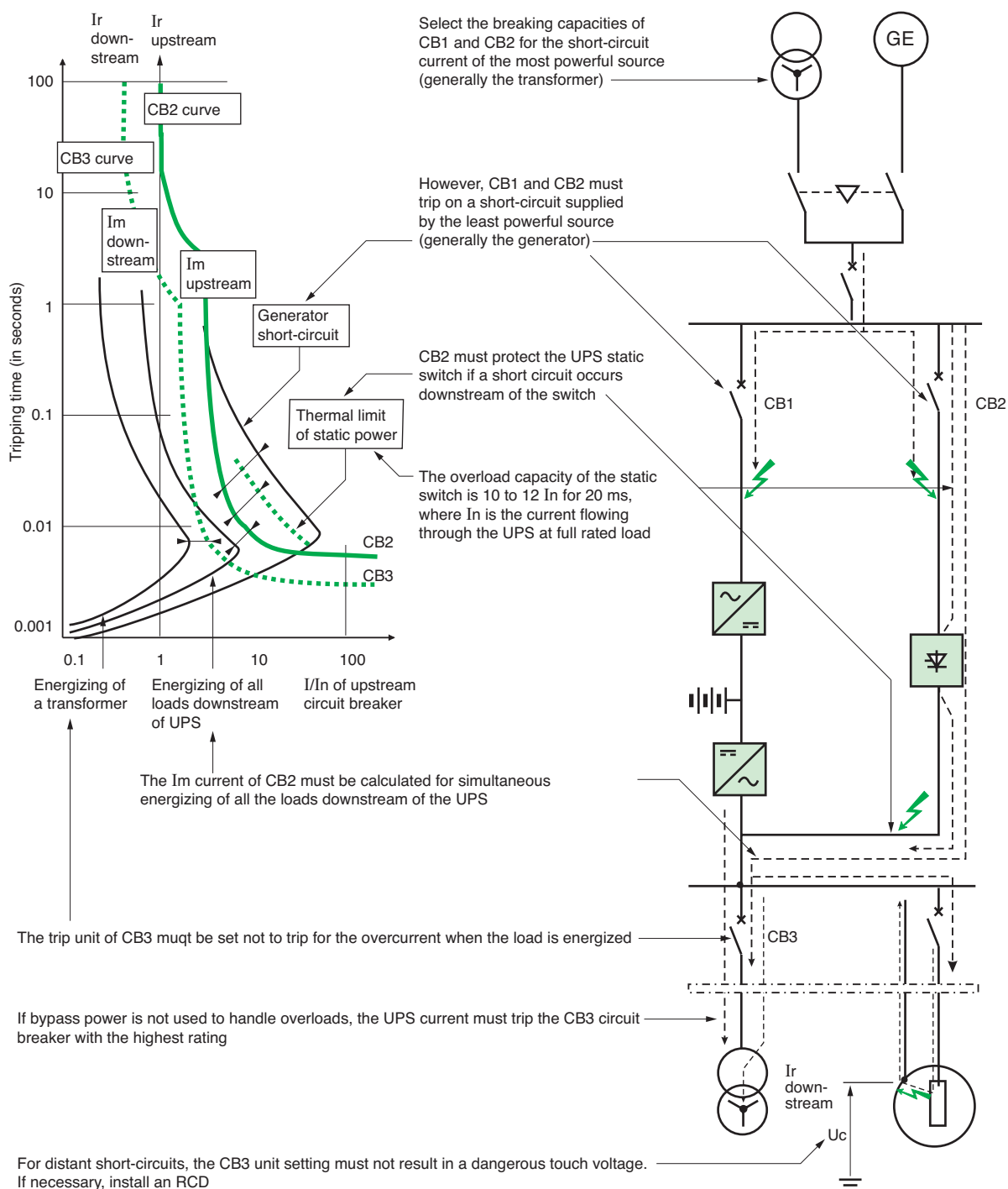


Fig. N25 : Circuit-breakers are submitted to a variety of situations

2 Uninterruptible Power Supply units (UPS)

Rating

The selected rating (rated current) for the circuit-breaker must be the one just above the rated current of the protected downstream cable.

Breaking capacity

The breaking capacity must be selected just above the short-circuit current that can occur at the point of installation.

Ir and Im thresholds

The table below indicates how to determine the Ir (overload ; thermal or longtime) and Im (short-circuit ; magnetic or short time) thresholds to ensure discrimination, depending on the upstream and downstream trip units.

Remark (see Fig. N26)

- Time discrimination must be implemented by qualified personnel because time delays before tripping increase the thermal stress (I^2t) downstream (cables, semi-conductors, etc.). Caution is required if tripping of CB2 is delayed using the Im threshold time delay
- Energy discrimination does not depend on the trip unit, only on the circuit-breaker

Type of downstream circuit	Ir upstream / Ir downstream ratio	Im upstream / Im downstream ratio	Im upstream / Im downstream ratio
Downstream trip unit	All types	Magnetic	Electronic
Distribution	> 1.6	>2	>1.5
Asynchronous motor	>3	>2	>1.5

Fig. N26 : Ir and Im thresholds depending on the upstream and downstream trip units

Special case of generator short-circuits

Figure N27 shows the reaction of a generator to a short-circuit.

To avoid any uncertainty concerning the type of excitation, we will trip at the first peak (3 to 5 I_n as per X"d) using the Im protection setting without a time delay.

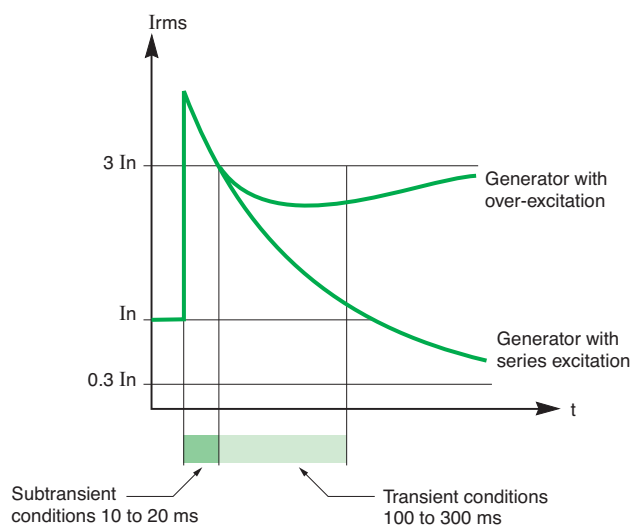


Fig. N27 : Generator during short-circuit

2.6 Installation, connection and sizing of cables

Ready-to-use UPS units

The low power UPSs, for micro computer systems for example, are compact ready-to-use equipment. The internal wiring is built in the factory and adapted to the characteristics of the devices.

Not ready-to-use UPS units

For the other UPSs, the wire connections to the power supply system, to the battery and to the load are not included.

Wiring connections depend on the current level as indicated in **Figure N28** below.

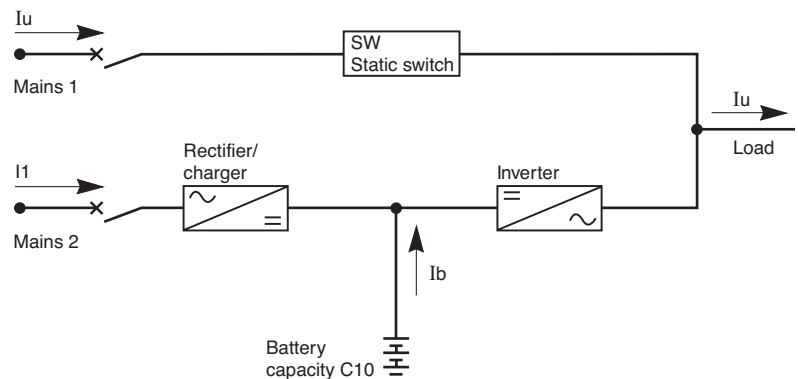


Fig.N28 : Current to be taken into account for the selection of the wire connections

Calculation of currents I_1 , I_u

- The input current I_u from the power network is the load current
- The input current I_1 of the charger/rectifier depends on:
 - The capacity of the battery (C_{10}) and the charging mode (I_b)
 - The characteristics of the charger
 - The efficiency of the inverter
- The current I_b is the current in the connection of the battery

These currents are given by the manufacturers.

Cable temperature rise and voltage drops

The cross section of cables depends on:

- Permissible temperature rise
- Permissible voltage drop

For a given load, each of these parameters results in a minimum permissible cross section. The larger of the two must be used.

When routing cables, care must be taken to maintain the required distances between control circuits and power circuits, to avoid any disturbances caused by HF currents.

Temperature rise

Permissible temperature rise in cables is limited by the withstand capacity of cable insulation.

Temperature rise in cables depends on:

- The type of core (Cu or Al)
- The installation method
- The number of touching cables

Standards stipulate, for each type of cable, the maximum permissible current.

Voltage drops

The maximum permissible voltage drops are:

- 3% for AC circuits (50 or 60 Hz)
- 1% for DC circuits

2 Uninterruptible Power Supply units (UPS)

Selection tables

Figure N29 indicates the voltage drop in percent for a circuit made up of 100 meters of cable. To calculate the voltage drop in a circuit with a length L, multiply the value in the table by L/100.

■ Sph: Cross section of conductors

■ I_n : Rated current of protection devices on circuit

Three-phase circuit

If the voltage drop exceeds 3% (50-60 Hz), increase the cross section of conductors.

DC circuit

If the voltage drop exceeds 1%, increase the cross section of conductors.

a - Three-phase circuits (copper conductors)

50-60 Hz - 380 V / 400 V / 415 V three-phase, $\cos \varphi = 0.8$, balanced system three-phase + N

I_n (A)	Sph (mm ²)											
	10	16	25	35	50	70	95	120	150	185	240	300
10	0.9											
15	1.2											
20	1.6	1.1										
25	2.0	1.3	0.9									
32	2.6	1.7	1.1									
40	3.3	2.1	1.4	1.0								
50	4.1	2.6	1.7	1.3	1.0							
63	5.1	3.3	2.2	1.6	1.2	0.9						
70	5.7	3.7	2.4	1.7	1.3	1.0	0.8					
80	6.5	4.2	2.7	2.1	1.5	1.2	0.9	0.7				
100	8.2	5.3	3.4	2.6	2.0	2.0	1.1	0.9	0.8			
125		6.6	4.3	3.2	2.4	2.4	1.4	1.1	1.0	0.8		
160			5.5	4.3	3.2	3.2	1.8	1.5	1.2	1.1	0.9	
200				5.3	3.9	3.9	2.2	1.8	1.6	1.3	1.2	0.9
250					4.9	4.9	2.8	2.3	1.9	1.7	1.4	1.2
320							3.5	2.9	2.5	2.1	1.9	1.5
400							4.4	3.6	3.1	2.7	2.3	1.9
500								4.5	3.9	3.4	2.9	2.4
600									4.9	4.2	3.6	3.0
800										5.3	4.4	3.8
1,000											6.5	4.7

For a three-phase 230 V circuit, multiply the result by e

For a single-phase 208/230 V circuit, multiply the result by 2

b - DC circuits (copper conductors)

I_n (A)	Sph (mm ²)											
	-	-	25	35	50	70	95	120	150	185	240	300
100			5.1	3.6	2.6	1.9	1.3	1.0	0.8	0.7	0.5	0.4
125				4.5	3.2	2.3	1.6	1.3	1.0	0.8	0.6	0.5
160					4.0	2.9	2.2	1.6	1.2	1.1	0.6	0.7
200						3.6	2.7	2.2	1.6	1.3	1.0	0.8
250							3.3	2.7	2.2	1.7	1.3	1.0
320								3.4	2.7	2.1	1.6	1.3
400									3.4	2.8	2.1	1.6
500										3.4	2.6	2.1
600										4.3	3.3	2.7
800											4.2	3.4
1,000											5.3	4.2
1,250												5.3

Fig. N29 : Voltage drop in percent for **[a]** three-phase circuits and **[b]** DC circuits

Special case for neutral conductors

In three-phase systems, the third-order harmonics (and their multiples) of single-phase loads add up in the neutral conductor (sum of the currents on the three phases).

For this reason, the following rule may be applied:

neutral cross section = 1.5 x phase cross section

Example

Consider a 70-meter 400 V three-phase circuit, with copper conductors and a rated current of 600 A.

Standard IEC 60364 indicates, depending on the installation method and the load, a minimum cross section.

We shall assume that the minimum cross section is 95 mm².

It is first necessary to check that the voltage drop does not exceed 3%.

The table for three-phase circuits on the previous page indicates, for a 600 A current flowing in a 300 mm² cable, a voltage drop of 3% for 100 meters of cable, i.e. for 70 meters:

$$3 \times \frac{70}{100} = 2.1 \%$$

Therefore less than 3%

A identical calculation can be run for a DC current of 1,000 A.

In a ten-meter cable, the voltage drop for 100 meters of 240 mm² cable is 5.3%, i.e. for ten meters:

$$5.3 \times \frac{10}{100} = 0.53 \%$$

Therefore less than 3%

2.7 The UPSs and their environment

The UPSs can communicate with electrical and computing environment. They can receive some data and provide information on their operation in order:

- To optimize the protection

For example, the UPS provides essential information on operating status to the computer system (load on inverter, load on static bypass, load on battery, low battery warning)

- To remotely control

The UPS provides measurement and operating status information to inform and allow operators to take specific actions

- To manage the installation

The operator has a building and energy management system which allow to obtain and save information from UPSs, to provide alarms and events and to take actions.

This evolution towards compatibility between computer equipment and UPSs has the effect to incorporate new built-in UPS functions.

2.8 Complementary equipment

Transformers

A two-winding transformer included on the upstream side of the static contactor of circuit 2 allows:

- A change of voltage level when the power network voltage is different to that of the load
- A change of system of earthing between the networks

Moreover, such a transformer :

- Reduces the short-circuit current level on the secondary, (i.e load) side compared with that on the power network side
- Prevents third harmonic currents which may be present on the secondary side from passing into the power-system network, providing that the primary winding is connected in delta.

Anti-harmonic filter

The UPS system includes a battery charger which is controlled by thyristors or transistors. The resulting regularly-chopped current cycles "generate" harmonic components in the power-supply network.

These undesirable components are filtered at the input of the rectifier and for most cases this reduces the harmonic current level sufficiently for all practical purposes.

2 Uninterruptible Power Supply units (UPS)

In certain specific cases however, notably in very large installations, an additional filter circuit may be necessary.

For example when :

- The power rating of the UPS system is large relative to the MV/LV transformer supplying it
- The LV busbars supply loads which are particularly sensitive to harmonics
- A diesel (or gas-turbine, etc.) driven alternator is provided as a standby power supply

In such cases, the manufacturer of the UPS system should be consulted

Communication equipment

Communication with equipment associated with computer systems may entail the need for suitable facilities within the UPS system. Such facilities may be incorporated in an original design (see **Fig. N30a**), or added to existing systems on request (see **Fig. N30b**).



Fig. N30a : Ready-to-use UPS unit (with DIN module)



Fig. N30b : UPS unit achieving disponibility and quality of computer system power supply

These transformers are generally in the range of several hundreds of VA to some hundreds of kVA and are frequently used for:

- Changing the low voltage level for:
 - Auxiliary supplies to control and indication circuits
 - Lighting circuits (230 V created when the primary system is 400 V 3-phase 3-wires)
- Changing the method of earthing for certain loads having a relatively high capacitive current to earth (computer equipment) or resistive leakage current (electric ovens, industrial-heating processes, mass-cooking installations, etc.)

LV/LV transformers are generally supplied with protective systems incorporated, and the manufacturers must be consulted for details. Overcurrent protection must, in any case, be provided on the primary side. The exploitation of these transformers requires a knowledge of their particular function, together with a number of points described below.

Note: In the particular cases of LV/LV safety isolating transformers at extra-low voltage, an earthed metal screen between the primary and secondary windings is frequently required, according to circumstances, as recommended in European Standard EN 60742.

3.1 Transformer-energizing inrush current

At the moment of energizing a transformer, high values of transient current (which includes a significant DC component) occur, and must be taken into account when considering protection schemes (see Fig. N31).

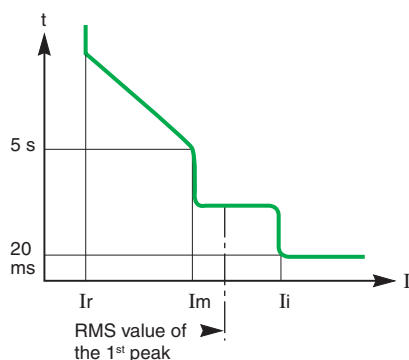


Fig N32 : Tripping characteristic of a Compact NS type STR (electronic)

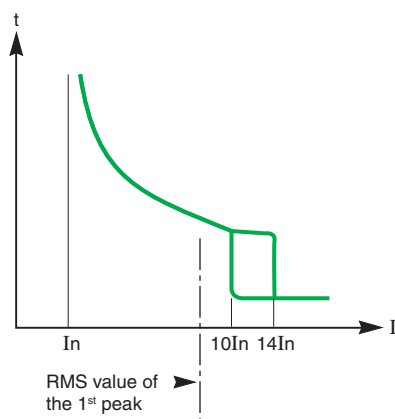


Fig N33 : Tripping characteristic of a Multi 9 curve D

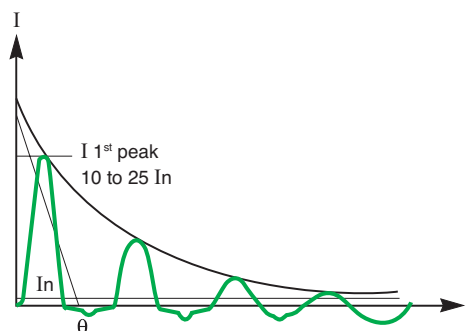


Fig N31 : Transformer-energizing inrush current

The magnitude of the current peak depends on:

- The value of voltage at the instant of energization
- The magnitude and polarity of the residual flux existing in the core of the transformer
- Characteristics of the load connected to the transformer

The first current peak can reach a value equal to 10 to 15 times the full-load r.m.s. current, but for small transformers (< 50 kVA) may reach values of 20 to 25 times the nominal full-load current. This transient current decreases rapidly, with a time constant θ of the order of several ms to several tens of ms.

3.2 Protection for the supply circuit of a LV/LV transformer

The protective device on the supply circuit for a LV/LV transformer must avoid the possibility of incorrect operation due to the magnetizing inrush current surge, noted above. It is necessary to use therefore:

- Selective (i.e. slightly time-delayed) circuit-breakers of the type Compact NS STR (see Fig. N32) or
- Circuit-breakers having a very high magnetic-trip setting, of the types Compact NS or Multi 9 curve D (see Fig. N33)

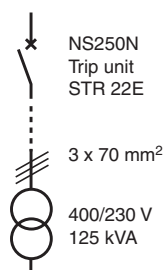


Fig N34 : Example

Example

A 400 V 3-phase circuit is supplying a 125 kVA 400/230 V transformer ($I_n = 180$ A) for which the first inrush current peak can reach $12 I_n$, i.e. $12 \times 180 = 2,160$ A. This current peak corresponds to a rms value of 1,530 A.

A compact NS 250N circuit-breaker with I_r setting of 200 A and I_m setting at $8 \times I_r$ would therefore be a suitable protective device.

A particular case: Overload protection installed at the secondary side of the transformer (see Fig. N34)

An advantage of overload protection located on the secondary side is that the short-circuit protection on the primary side can be set at a high value, or alternatively a circuit-breaker type MA (magnetic only) can be used. The primary side short-circuit protection setting must, however, be sufficiently sensitive to ensure its operation in the event of a short-circuit occurring on the secondary side of the transformer.

Note: The primary protection is sometimes provided by fuses, type aM. This practice has two disadvantages:

- The fuses must be largely oversized (at least 4 times the nominal full-load rated current of the transformer)
- In order to provide isolating facilities on the primary side, either a load-break switch or a contactor must be associated with the fuses.

3.3 Typical electrical characteristics of LV/LV 50 Hz transformers**3-phase**

kVA rating	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800
No-load losses (W)	100	110	130	150	160	170	270	310	350	350	410	460	520	570	680	680	790	950	1160	1240	1485	1855	2160
Full-load losses (W)	250	320	390	500	600	840	800	1180	1240	1530	1650	2150	2540	3700	3700	5900	5900	6500	7400	9300	9400	11400	13400
Short-circuit voltage (%)	4.5	4.5	4.5	5.5	5.5	5.5	5.5	5.5	5	5	4.5	5	5	5.5	4.5	5.5	5	5	4.5	6	6	5.5	5.5

1-phase

kVA rating	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160
No-load losses (W)	105	115	120	140	150	175	200	215	265	305	450	450	525	635
Full-load losses (W)	400	530	635	730	865	1065	1200	1400	1900	2000	2450	3950	3950	4335
Short-circuit voltage (%)	5	5	5	4.5	4.5	4.5	4	4	5	5	4.5	5.5	5	5

3.4 Protection of LV/LV transformers, using Merlin Gerin circuit-breakers**Multi 9 circuit-breaker**

Transformer power rating (kVA)			Circuit breaker curve D or K	Size (A)
230/240 V 1-ph	230/240 V 3-ph 400/415 V 1-ph	400/415 V 3-ph		
0.05	0.09	0.16	C60, NG125	0.5
0.11	0.18	0.32	C60, NG125	1
0.21	0.36	0.63	C60, NG125	2
0.33	0.58	1.0	C60, NG125	3
0.67	1.2	2.0	C60, NG125	6
1.1	1.8	3.2	C60, C120, NG125	10
1.7	2.9	5.0	C60, C120, NG125	16
2.1	3.6	6.3	C60, C120, NG125	20
2.7	4.6	8.0	C60, C120, NG125	25
3.3	5.8	10	C60, C120, NG125	32
4.2	7.2	13	C60, C120, NG125	40
5.3	9.2	16	C60, C120, NC100, NG125	50
6.7	12	20	C60, C120, NC100, NG125	63
8.3	14	25	C120, NC100, NG125	80
11	18	32	C120, NC100, NG125	100
13	23	40	C120, NG125	125

N25

Compact NSX100 to NSX250 circuit-breakers with TM-D trip units

Transformer power rating (kVA)			Circuit-breaker	Trip unit
230/240 V 1-ph	230/240 V 3-ph 400/415 V 1-ph	400/415 V 3-ph		
3	5...6	9...12	NSX100B/F/N/H/S/L	TM16D
5	8...9	14...16	NSX100B/F/N/H/S/L	TM25D
7...9	13...16	22...28	NSX100B/F/N/H/S/L	TM40D
12...15	20...25	35...44	NSX100B/F/N/H/S/L	TM63D
16...19	26...32	45...56	NSX100B/F/N/H/S/L	TM80D
18...23	32...40	55...69	NSX160B/F/N/H/S/L	TM100D
23...29	40...50	69...87	NSX160B/F/N/H/S/L	TM125D
29...37	51...64	89...111	NSX250B/F/N/H/S/L	TM160D
37...46	64...80	111...139	NSX250B/F/N/H/S/L	TM200D

Compact NSX100 to NS1600 / Masterpact circuit-breakers with Micrologic trip units

Transformer power rating (kVA)			Circuit-breaker	Trip unit	Setting Ir max
230/240 V 1-ph	230/240 V 3-ph 400/415 V 1-ph	400/415 V 3-ph			
4...7	6...13	11...22	NSX100B/F/N/H/S/L	Micrologic 2.2 or 6.2 40	0.8
9...19	16...30	27...56	NSX100B/F/N/H/S/L	Micrologic 2.2 or 6.2 100	0.8
15...30	5...50	44...90	NSX160B/F/N/H/S/L	Micrologic 2.2 or 6.2 160	0.8
23...46	40...80	70...139	NSX250B/F/N/H/S/L	Micrologic 2.2 or 6.2 250	0.8
37...65	64...112	111...195	NSX400F/N/H/S	Micrologic 2.3 or 6.3 400	0.7
37...55	64...95	111...166	NSX400L	Micrologic 2.3 or 6.3 400	0.6
58...83	100...144	175...250	NSX630F/N/H/S/L	Micrologic 2.3 or 6.3 630	0.6
58...150	100...250	175...436	NS630bN/bH NT06H1	Micrologic 5.0/6.0/7.0	1
74...184	107...319	222...554	NS800N/H - NT08H1 - NW08N1/H1	Micrologic 5.0/6.0/7.0	1
90...230	159...398	277...693	NS1000N/H - NT10H1 - NW10N1/H1	Micrologic 5.0/6.0/7.0	1
115...288	200...498	346...866	NS1250N/H - NT12H1 - NW12N1/H1	Micrologic 5.0/6.0/7.0	1
147...368	256...640	443...1,108	NS1600N/H - NT16H1 - NW16N1/H1	Micrologic 5.0/6.0/7.0	1
184...460	320...800	554...1,385	NW20N1/H1	Micrologic 5.0/6.0/7.0	1
230...575	400...1,000	690...1,730	NW25H2/H3	Micrologic 5.0/6.0/7.0	1
294...736	510...1,280	886...2,217	NW32H2/H3	Micrologic 5.0/6.0/7.0	1

A source of comfort and productivity, lighting represents 15% of the quantity of electricity consumed in industry and 40% in buildings. The quality of lighting (light stability and continuity of service) depends on the quality of the electrical energy thus consumed. The supply of electrical power to lighting networks has therefore assumed great importance.

To help with their design and simplify the selection of appropriate protection devices, an analysis of the different lamp technologies is presented. The distinctive features of lighting circuits and their impact on control and protection devices are discussed. Recommendations relative to the difficulties of lighting circuit implementation are given.

4.1 The different lamp technologies

Artificial luminous radiation can be produced from electrical energy according to two principles: incandescence and electroluminescence.

Incandescence is the production of light via temperature elevation. The most common example is a filament heated to white state by the circulation of an electrical current. The energy supplied is transformed into heat by the Joule effect and into luminous flux.

Luminescence is the phenomenon of emission by a material of visible or almost visible luminous radiation. A gas (or vapors) subjected to an electrical discharge emits luminous radiation (Electroluminescence of gases).

Since this gas does not conduct at normal temperature and pressure, the discharge is produced by generating charged particles which permit ionization of the gas. The nature, pressure and temperature of the gas determine the light spectrum.

Photoluminescence is the luminescence of a material exposed to visible or almost visible radiation (ultraviolet, infrared).

When the substance absorbs ultraviolet radiation and emits visible radiation which stops a short time after energization, this is fluorescence.

Incandescent lamps

Incandescent lamps are historically the oldest and the most often found in common use.

They are based on the principle of a filament rendered incandescent in a vacuum or neutral atmosphere which prevents combustion.

A distinction is made between:

■ Standard bulbs

These contain a tungsten filament and are filled with an inert gas (nitrogen and argon or krypton).

■ Halogen bulbs

These also contain a tungsten filament, but are filled with a halogen compound and an inert gas (krypton or xenon). This halogen compound is responsible for the phenomenon of filament regeneration, which increases the service life of the lamps and avoids them blackening. It also enables a higher filament temperature and therefore greater luminosity in smaller-size bulbs.

The main disadvantage of incandescent lamps is their significant heat dissipation, resulting in poor luminous efficiency.

Fluorescent lamps

This family covers fluorescent tubes and compact fluorescent lamps. Their technology is usually known as "low-pressure mercury".

In fluorescent tubes, an electrical discharge causes electrons to collide with ions of mercury vapor, resulting in ultraviolet radiation due to energization of the mercury atoms. The fluorescent material, which covers the inside of the tubes, then transforms this radiation into visible light.

Fluorescent tubes dissipate less heat and have a longer service life than incandescent lamps, but they do need an ignition device called a "starter" and a device to limit the current in the arc after ignition. This device called "ballast" is usually a choke placed in series with the arc.

Compact fluorescent lamps are based on the same principle as a fluorescent tube. The starter and ballast functions are provided by an electronic circuit (integrated in the lamp) which enables the use of smaller tubes folded back on themselves.

Compact fluorescent lamps (see **Fig. N35**) were developed to replace incandescent lamps: They offer significant energy savings (15 W against 75 W for the same level of brightness) and an increased service life.

Lamps known as "induction" type or "without electrodes" operate on the principle of ionization of the gas present in the tube by a very high frequency electromagnetic field (up to 1 GHz). Their service life can be as long as 100,000 hrs.

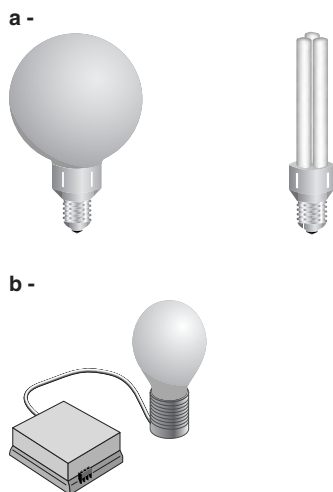


Fig. N35 : Compact fluorescent lamps [a] standard, [b] induction

N27

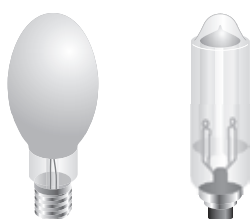


Fig. N36 : Discharge lamps

Discharge lamps (see Fig. N36)

The light is produced by an electrical discharge created between two electrodes within a gas in a quartz bulb. All these lamps therefore require a ballast to limit the current in the arc. A number of technologies have been developed for different applications.

Low-pressure sodium vapor lamps have the best light output, however the color rendering is very poor since they only have a monochromatic orange radiation.

High-pressure sodium vapor lamps produce a white light with an orange tinge.

In high-pressure mercury vapor lamps, the discharge is produced in a quartz or ceramic bulb at high pressure. These lamps are called "fluorescent mercury discharge lamps". They produce a characteristically bluish white light.

Metal halide lamps are the latest technology. They produce a color with a broad color spectrum. The use of a ceramic tube offers better luminous efficiency and better color stability.

Light Emitting Diodes (LED)

The principle of light emitting diodes is the emission of light by a semi-conductor as an electrical current passes through it. LEDs are commonly found in numerous applications, but the recent development of white or blue diodes with a high light output opens new perspectives, especially for signaling (traffic lights, exit signs or emergency lighting).

LEDs are low-voltage and low-current devices, thus suitable for battery-supply.

A converter is required for a line power supply.

The advantage of LEDs is their low energy consumption. As a result, they operate at a very low temperature, giving them a very long service life. Conversely, a simple diode has a weak light intensity. A high-power lighting installation therefore requires connection of a large number of units in series and parallel.

Technology	Application	Advantages	Disadvantages
Standard incandescent	- Domestic use - Localized decorative lighting	- Direct connection without intermediate switchgear - Reasonable purchase price - Compact size - Instantaneous lighting - Good color rendering	- Low luminous efficiency and high electricity consumption - Significant heat dissipation - Short service life
Halogen incandescent	- Spot lighting - Intense lighting	- Direct connection - Instantaneous efficiency - Excellent color rendering	- Average luminous efficiency
Fluorescent tube	- Shops, offices, workshops - Outdoors	- High luminous efficiency - Average color rendering	- Low light intensity of single unit - Sensitive to extreme temperatures
Compact fluorescent lamp	- Domestic use - Offices - Replacement of incandescent lamps	- Good luminous efficiency - Good color rendering	- High initial investment compared to incandescent lamps
HP mercury vapor	- Workshops, halls, hangars - Factory floors	- Good luminous efficiency - Acceptable color rendering - Compact size - Long service life	- Lighting and relighting time of a few minutes
High-pressure sodium	- Outdoors - Large halls	- Very good luminous efficiency	- Lighting and relighting time of a few minutes
Low-pressure sodium	- Outdoors - Emergency lighting	- Good visibility in foggy weather - Economical to use	- Long lighting time (5 min.) - Mediocre color rendering
Metal halide	- Large areas - Halls with high ceilings	- Good luminous efficiency - Good color rendering - Long service life	- Lighting and relighting time of a few minutes
LED	- Signaling (3-color traffic lights, "exit" signs and emergency lighting)	- Insensitive to the number of switching operations - Low energy consumption - Low temperature	- Limited number of colors - Low brightness of single unit

Technology	Power (watt)	Efficiency (lumen/watt)	Service life (hours)
Standard incandescent	3 – 1,000	10 – 15	1,000 – 2,000
Halogen incandescent	5 – 500	15 – 25	2,000 – 4,000
Fluorescent tube	4 – 56	50 – 100	7,500 – 24,000
Compact fluorescent lamp	5 – 40	50 – 80	10,000 – 20,000
HP mercury vapor	40 – 1,000	25 – 55	16,000 – 24,000
High-pressure sodium	35 – 1,000	40 – 140	16,000 – 24,000
Low-pressure sodium	35 – 180	100 – 185	14,000 – 18,000
Metal halide	30 – 2,000	50 – 115	6,000 – 20,000
LED	0.05 – 0.1	10 – 30	40,000 – 100,000

Fig. N37 : Usage and technical characteristics of lighting devices

4.2 Electrical characteristics of lamps

Incandescent lamps with direct power supply

Due to the very high temperature of the filament during operation (up to 2,500 °C), its resistance varies greatly depending on whether the lamp is on or off. As the cold resistance is low, a current peak occurs on ignition that can reach 10 to 15 times the nominal current for a few milliseconds or even several milliseconds.

This constraint affects both ordinary lamps and halogen lamps: it imposes a reduction in the maximum number of lamps that can be powered by devices such as remote-control switches, modular contactors and relays for busbar trunking.

Extra Low Voltage (ELV) halogen lamps

■ Some low-power halogen lamps are supplied with ELV 12 or 24 V, via a transformer or an electronic converter. With a transformer, the magnetization phenomenon combines with the filament resistance variation phenomenon at switch-on. The inrush current can reach 50 to 75 times the nominal current for a few milliseconds. The use of dimmer switches placed upstream significantly reduces this constraint.

■ Electronic converters, with the same power rating, are more expensive than solutions with a transformer. This commercial handicap is compensated by a greater ease of installation since their low heat dissipation means they can be fixed on a flammable support. Moreover, they usually have built-in thermal protection.

New ELV halogen lamps are now available with a transformer integrated in their base. They can be supplied directly from the LV line supply and can replace normal lamps without any special adaptation.

Dimming for incandescent lamps

This can be obtained by varying the voltage applied to the lampere

This voltage variation is usually performed by a device such as a Triac dimmer switch, by varying its firing angle in the line voltage period. The wave form of the voltage applied to the lamp is illustrated in **Figure N38a**. This technique known as “cut-on control” is suitable for supplying power to resistive or inductive circuits. Another technique suitable for supplying power to capacitive circuits has been developed with MOS or IGBT electronic components. This technique varies the voltage by blocking the current before the end of the half-period (see **Fig. N38b**) and is known as “cut-off control”.

Switching on the lamp gradually can also reduce, or even eliminate, the current peak on ignition.

As the lamp current is distorted by the electronic switching, harmonic currents are produced. The 3rd harmonic order is predominant, and the percentage of 3rd harmonic current related to the maximum fundamental current (at maximum power) is represented on **Figure N39**.

Note that in practice, the power applied to the lamp by a dimmer switch can only vary in the range between 15 and 85% of the maximum power of the lampere

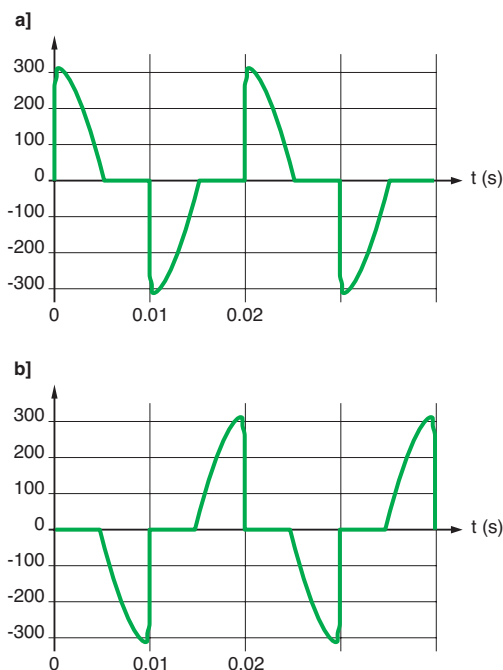


Fig. N38 : Shape of the voltage supplied by a light dimmer at 50% of maximum voltage with the following techniques:

a) “cut-on control”
b) “cut-off control”

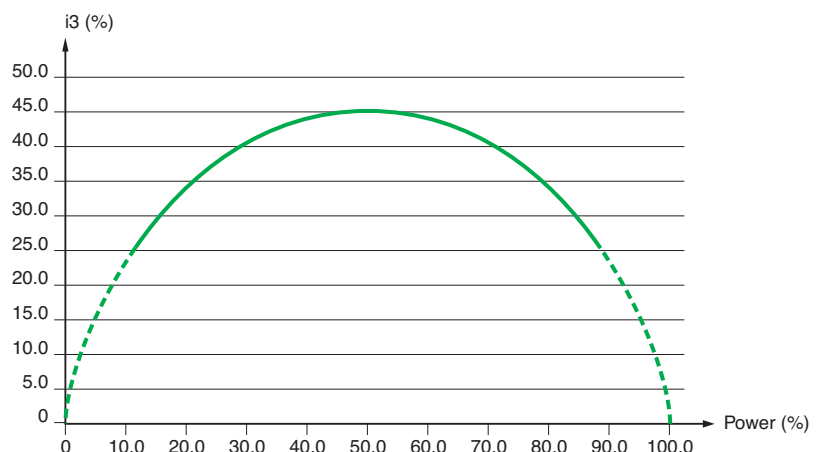


Fig. N39 : Percentage of 3rd harmonic current as a function of the power applied to an incandescent lamp using an electronic dimmer switch

According to IEC standard 61000-3-2 setting harmonic emission limits for electric or electronic systems with current ≤ 16 A, the following arrangements apply:

- Independent dimmers for incandescent lamps with a rated power less than or equal to 1 kW have no limits applied
- Otherwise, or for incandescent lighting equipment with built-in dimmer or dimmer built in an enclosure, the maximum permissible 3rd harmonic current is equal to 2.30 A

Fluorescent lamps with magnetic ballast

Fluorescent tubes and discharge lamps require the intensity of the arc to be limited, and this function is fulfilled by a choke (or magnetic ballast) placed in series with the bulb itself (see Fig. N40).

This arrangement is most commonly used in domestic applications with a limited number of tubes. No particular constraint applies to the switches.

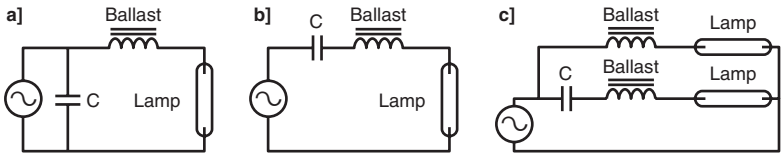
Dimmer switches are not compatible with magnetic ballasts: the cancellation of the voltage for a fraction of the period interrupts the discharge and totally extinguishes the lampere

The starter has a dual function: preheating the tube electrodes, and then generating an overvoltage to ignite the tube. This overvoltage is generated by the opening of a contact (controlled by a thermal switch) which interrupts the current circulating in the magnetic ballast.

During operation of the starter (approx. 1 s), the current drawn by the luminaire is approximately twice the nominal current.

Since the current drawn by the tube and ballast assembly is essentially inductive, the power factor is very low (on average between 0.4 and 0.5). In installations consisting of a large number of tubes, it is necessary to provide compensation to improve the power factor.

For large lighting installations, centralized compensation with capacitor banks is a possible solution, but more often this compensation is included at the level of each luminaire in a variety of different layouts (see Fig. N41).



Compensation layout	Application	Comments
Without compensation	Domestic	Single connection
Parallel [a]	Offices, workshops, superstores	Risk of overcurrents for control devices
Series [b]		Choose capacitors with high operating voltage (450 to 480 V)
Duo [c]		Avoids flicker

Fig. N41 : The various compensation layouts: a) parallel; b) series; c) dual series also called "duo" and their fields of application

The compensation capacitors are therefore sized so that the global power factor is greater than 0.85. In the most common case of parallel compensation, its capacity is on average 1 μ F for 10 W of active power, for any type of lampere However, this compensation is incompatible with dimmer switches.

Constraints affecting compensation

The layout for parallel compensation creates constraints on ignition of the lampere Since the capacitor is initially discharged, switch-on produces an overcurrent. An overvoltage also appears, due to the oscillations in the circuit made up of the capacitor and the power supply inductance.

The following example can be used to determine the orders of magnitude.

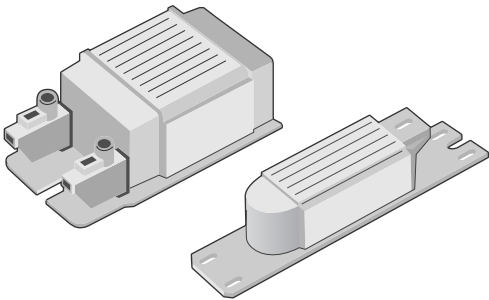


Fig. N40 : Magnetic ballasts

N30

Assuming an assembly of 50 fluorescent tubes of 36 W each:

- Total active power: 1,800 W
- Apparent power: 2 kVA
- Total rms current: 9 A
- Peak current: 13 A

With:

- A total capacity: $C = 175 \mu\text{F}$
- A line inductance (corresponding to a short-circuit current of 5 kA): $L = 150 \mu\text{H}$

The maximum peak current at switch-on equals:

$$I_c = V_{\max} \sqrt{\frac{C}{L}} = 230\sqrt{2} \sqrt{\frac{175 \times 10^{-6}}{150 \times 10^{-6}}} = 350 \text{ A}$$

The theoretical peak current at switch-on can therefore reach **27 times** the peak current during normal operation.

The shape of the voltage and current at ignition is given in **Figure N42** for switch closing at the line supply voltage peak.

There is therefore a risk of contact welding in electromechanical control devices (remote-control switch, contactor, circuit-breaker) or destruction of solid state switches with semi-conductors.

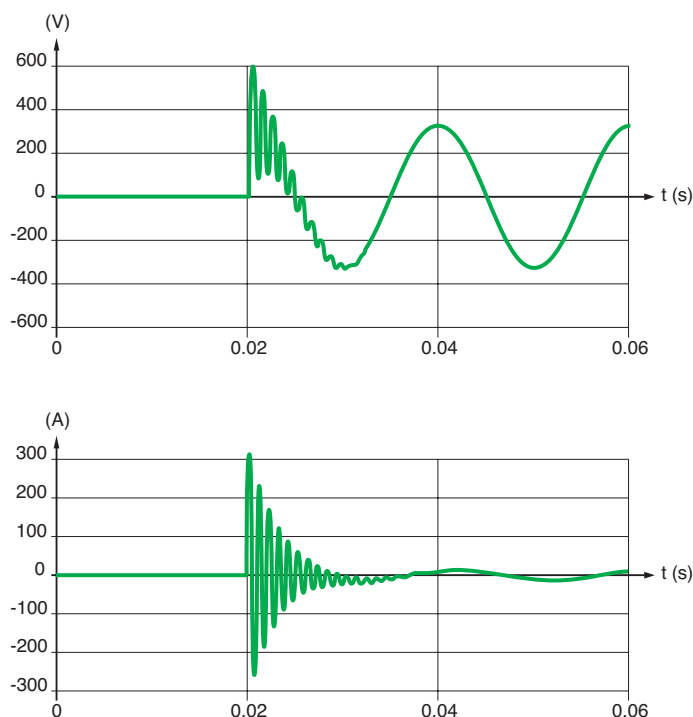


Fig. N42 : Power supply voltage at switch-on and inrush current

In reality, the constraints are usually less severe, due to the impedance of the cables. Ignition of fluorescent tubes in groups implies one specific constraint. When a group of tubes is already switched on, the compensation capacitors in these tubes which are already energized participate in the inrush current at the moment of ignition of a second group of tubes: they “amplify” the current peak in the control switch at the moment of ignition of the second group.

The table in **Figure N43**, resulting from measurements, specifies the magnitude of the first current peak, for different values of prospective short-circuit current I_{sc} . It is seen that the current peak can be multiplied by 2 or 3, depending on the number of tubes already in use at the moment of connection of the last group of tubes.

Number of tubes already in use	Number of tubes connected	Inrush current peak (A)		
		$I_{sc} = 1,500\text{ A}$	$I_{sc} = 3,000\text{ A}$	$I_{sc} = 6,000\text{ A}$
0	14	233	250	320
14	14	558	556	575
28	14	608	607	624
42	14	618	616	632

Fig. N43 : Magnitude of the current peak in the control switch of the moment of ignition of a second group of tubes

Nonetheless, sequential ignition of each group of tubes is recommended so as to reduce the current peak in the main switch.

The most recent magnetic ballasts are known as “low-loss”. The magnetic circuit has been optimized, but the operating principle remains the same. This new generation of ballasts is coming into widespread use, under the influence of new regulations (European Directive, Energy Policy Act - USA).

In these conditions, the use of electronic ballasts is likely to increase, to the detriment of magnetic ballasts.

Fluorescent lamps with electronic ballast

Electronic ballasts are used as a replacement for magnetic ballasts to supply power to fluorescent tubes (including compact fluorescent lamps) and discharge lamps. They also provide the “starter” function and do not need any compensation capacity.

The principle of the electronic ballast (see **Fig. N44**) consists of supplying the lamp arc via an electronic device that generates a rectangular form AC voltage with a frequency between 20 and 60 kHz.

Supplying the arc with a high-frequency voltage can totally eliminate the flicker phenomenon and strobe effects. The electronic ballast is totally silent.

During the preheating period of a discharge lamp, this ballast supplies the lamp with increasing voltage, imposing an almost constant current. In steady state, it regulates the voltage applied to the lamp independently of any fluctuations in the line voltage.

Since the arc is supplied in optimum voltage conditions, this results in energy savings of 5 to 10% and increased lamp service life. Moreover, the efficiency of the electronic ballast can exceed 93%, whereas the average efficiency of a magnetic device is only 85%.

The power factor is high (> 0.9).

The electronic ballast is also used to provide the light dimming function. Varying the frequency in fact varies the current magnitude in the arc and hence the luminous intensity.

Inrush current

The main constraint that electronic ballasts bring to line supplies is the high inrush current on switch-on linked to the initial load of the smoothing capacitors (see **Fig. N45**).

Technology	Max. inrush current	Duration
Rectifier with PFC	30 to 100 In	$\leq 1\text{ ms}$
Rectifier with choke	10 to 30 In	$\leq 5\text{ ms}$
Magnetic ballast	$\leq 13\text{ In}$	5 to 10 ms

Fig. N45 : Orders of magnitude of the inrush current maximum values, depending on the technologies used

N32

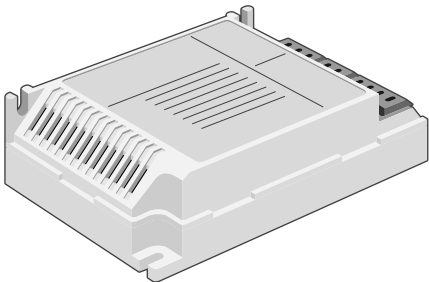


Fig. N44 : Electronic ballast

In reality, due to the wiring impedances, the inrush currents for an assembly of lamps is much lower than these values, in the order of 5 to 10 I_n for less than 5 ms. Unlike magnetic ballasts, this inrush current is not accompanied by an overvoltage.

Harmonic currents

For ballasts associated with high-power discharge lamps, the current drawn from the line supply has a low total harmonic distortion (< 20% in general and < 10% for the most sophisticated devices). Conversely, devices associated with low-power lamps, in particular compact fluorescent lamps, draw a very distorted current (see **Fig. N46**). The total harmonic distortion can be as high as 150%. In these conditions, the rms current drawn from the line supply equals 1.8 times the current corresponding to the lamp active power, which corresponds to a power factor of 0.55.

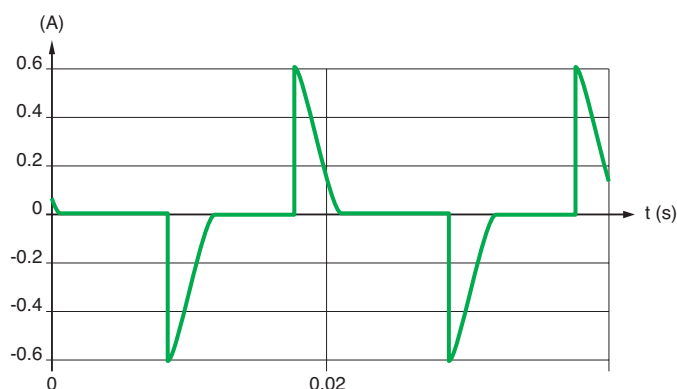


Fig. N46 : Shape of the current drawn by a compact fluorescent lamp

In order to balance the load between the different phases, lighting circuits are usually connected between phases and neutral in a balanced way. In these conditions, the high level of third harmonic and harmonics that are multiple of 3 can cause an overload of the neutral conductor. The least favorable situation leads to a neutral current which may reach $\sqrt{3}$ times the current in each phase.

Harmonic emission limits for electric or electronic systems are set by IEC standard 61000-3-2. For simplification, the limits for lighting equipment are given here only for harmonic orders 3 and 5 which are the most relevant (see **Fig. N47**).

Harmonic order	Active input power > 25W	Active input power ≤ 25W one of the 2 sets of limits apply:	
	% of fundamental current	% of fundamental current	Harmonic current relative to active power
3	30	86	3.4 mA/W
5	10	61	1.9 mA/W

Fig. N47 : Maximum permissible harmonic current

Leakage currents

Electronic ballasts usually have capacitors placed between the power supply conductors and the earth. These interference-suppressing capacitors are responsible for the circulation of a permanent leakage current in the order of 0.5 to 1 mA per ballast. This therefore results in a limit being placed on the number of ballasts that can be supplied by a Residual Current Differential Safety Device (RCD).

At switch-on, the initial load of these capacitors can also cause the circulation of a current peak whose magnitude can reach several amps for 10 μ s. This current peak may cause unwanted tripping of unsuitable devices.

High-frequency emissions

Electronic ballasts are responsible for high-frequency conducted and radiated emissions.

The very steep rising edges applied to the ballast output conductors cause current pulses circulating in the stray capacities to earth. As a result, stray currents circulate in the earth conductor and the power supply conductors. Due to the high frequency of these currents, there is also electromagnetic radiation. To limit these HF emissions, the lamp should be placed in the immediate proximity of the ballast, thus reducing the length of the most strongly radiating conductors.

The different power supply modes (see Fig. N48)

Technology	Power supply mode	Other device
Standard incandescent	Direct power supply	Dimmer switch
Halogen incandescent		
ELV halogen incandescent	Transformer	Electronic converter
Fluorescent tube	Magnetic ballast and starter	Electronic ballast
Compact fluorescent lamp		Electronic dimmer + ballast
Mercury vapor	Built-in electronic ballast	
High-pressure sodium	Magnetic ballast	Electronic ballast
Low-pressure sodium		
Metal halide		

Fig. N48 : Different power supply modes

4.3 Constraints related to lighting devices and recommendations

The current actually drawn by luminaires

The risk

This characteristic is the first one that should be defined when creating an installation, otherwise it is highly probable that overload protection devices will trip and users may often find themselves in the dark.

It is evident that their determination should take into account the consumption of all components, especially for fluorescent lighting installations, since the power consumed by the ballasts has to be added to that of the tubes and bulbs.

The solution

For incandescent lighting, it should be remembered that the line voltage can be more than 10% of its nominal value, which would then cause an increase in the current drawn.

For fluorescent lighting, unless otherwise specified, the power of the magnetic ballasts can be assessed at 25% of that of the bulbs. For electronic ballasts, this power is lower, in the order of 5 to 10%.

The thresholds for the overcurrent protection devices should therefore be calculated as a function of the total power and the power factor, calculated for each circuit.

Overcurrents at switch-on

The risk

The devices used for control and protection of lighting circuits are those such as relays, triac, remote-control switches, contactors or circuit-breakers.

The main constraint applied to these devices is the current peak on energization. This current peak depends on the technology of the lamps used, but also on the installation characteristics (supply transformer power, length of cables, number of lamps) and the moment of energization in the line voltage period. A high current peak, however fleeting, can cause the contacts on an electromechanical control device to weld together or the destruction of a solid state device with semi-conductors.

Two solutions

Because of the inrush current, the majority of ordinary relays are incompatible with lighting device power supply. The following recommendations are therefore usually made:

- Limit the number of lamps to be connected to a single device so that their total power is less than the maximum permissible power for the device
- Check with the manufacturers what operating limits they suggest for the devices. This precaution is particularly important when replacing incandescent lamps with compact fluorescent lamps

By way of example, the table in **Figure N49** indicates the maximum number of compensated fluorescent tubes that can be controlled by different devices with 16 A rating. Note that the number of controlled tubes is well below the number corresponding to the maximum power for the devices.

Tube unit power requirement (W)	Number of tubes corresponding to the power 16 A x 230 V	Maximum number of tubes that can be controlled by		
		Contactors GC16 A CT16 A	Remote control switches TL16 A	Circuit-breakers C60-16 A
18	204	15	50	112
36	102	15	25	56
58	63	10	16	34

Fig. N49 : The number of controlled tubes is well below the number corresponding to the maximum power for the devices

But a technique exists to limit the current peak on energization of circuits with capacitive behavior (magnetic ballasts with parallel compensation and electronic ballasts). It consists of ensuring that activation occurs at the moment when the line voltage passes through zero. Only solid state switches with semi-conductors offer this possibility (see **Fig. N50a**). This technique has proved to be particularly useful when designing new lighting circuits.

More recently, hybrid technology devices have been developed that combine a solid state switch (activation on voltage passage through zero) and an electromechanical contactor short-circuiting the solid state switch (reduction of losses in the semi-conductors) (see **Fig. N50b**).

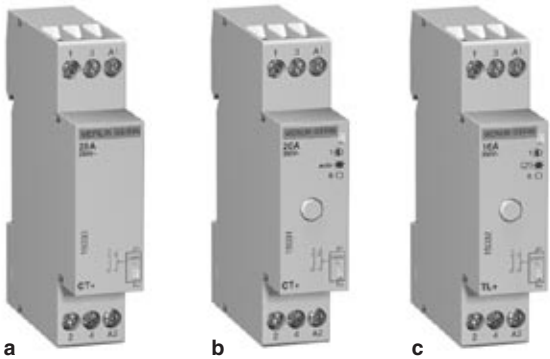


Fig. N50 : “Standard” CT+ contactor [a], CT+ contactor with manual override, pushbutton for selection of operating mode and indicator lamp showing the active operating mode [b], and TL + remote-control switch [c] (Merlin Gerin brand)

Modular contactors and impulse relays do not use the same technologies. Their rating is determined according to different standards. For example, for a given rating, an impulse relay is more efficient than a modular contactor for the control of light fittings with a strong inrush current, or with a low power factor (non-compensated inductive circuit).

Choice of relay rating according to lamp type

■ **Figure 51** below shows the maximum number of light fittings for each relay, according to the type, power and configuration of a given lamp. As an indication, the total acceptable power is also mentioned.

■ These values are given for a 230 V circuit with 2 active conductors (single-phase phase/neutral or two-phase phase/phase). For 110 V circuits, divide the values in the table by 2.

■ To obtain the equivalent values for the whole of a 230 V three-phase circuit, multiply the number of lamps and the total acceptable power:

- by $\sqrt{3}$ (1.73) for circuits without neutral;
- by 3 for circuits with neutral.

Note: The power ratings of the lamps most commonly used are shown in bold.

Type of lamp	Unit power and capacitance of power factor correction capacitor	Maximum number of light fittings for a single-phase circuit and maximum power output per circuit											
		TL impulse relay				CT contactor							
		16 A	32 A	16 A	25 A	40 A	63 A						
Basic incandescent lamps													
LV halogen lamps													
Replacement mercury vapour lamps (without ballast)													
	40 W	40	1500 W	106	4000 W	38	1550 W	57	2300 W	115	4600 W	172	6900 W
	60 W	25	to	66	to	30	to	45	to	85	to	125	to
	75 W	20	1600 W	53	4200 W	25	2000 W	38	2850 W	70	5250 W	100	7500 W
	100 W	16		42		19		28		50		73	
	150 W	10		28		12		18		35		50	
	200 W	8		21		10		14		26		37	
	300 W	5	1500 W	13	4000 W	7	2100 W	10	3000 W	18	5500 W	25	7500 W
	500 W	3		8		4		6		10	to	15	to
	1000 W	1		4		2		3		6	6000 W	8	8000 W
	1500 W	1		2		1		2		4		5	
ELV 12 or 24 V halogen lamps													
With ferromagnetic transformer	20 W	70	1350 W	180	3600 W	15	300 W	23	450 W	42	850 W	63	1250 W
	50 W	28	to	74	to	10	to	15	to	27	to	42	to
	75 W	19	1450 W	50	3750 W	8	600 W	12	900 W	23	1950 W	35	2850 W
	100 W	14		37		6		8		18		27	
With electronic transformer	20 W	60	1200 W	160	3200 W	62	1250 W	90	1850 W	182	3650 W	275	5500 W
	50 W	25	to	65	to	25	to	39	to	76	to	114	to
	75 W	18	1400 W	44	3350 W	20	1600 W	28	2250 W	53	4200 W	78	6000 W
	100 W	14		33		16		22		42		60	
Fluorescent tubes with starter and ferromagnetic ballast													
1 tube without compensation (1)	15 W	83	1250 W	213	3200 W	22	330 W	30	450 W	70	1050 W	100	1500 W
	18 W	70	to	186	to	22	to	30	to	70	to	100	to
	20 W	62	1300 W	160	3350 W	22	850 W	30	1200 W	70	2400 W	100	3850 W
	36 W	35		93		20		28		60		90	
	40 W	31		81		20		28		60		90	
	58 W	21		55		13		17		35		56	
	65 W	20		50		13		17		35		56	
	80 W	16		41		10		15		30		48	
	115 W	11		29		7		10		20		32	
	15 W	60	900 W	160	2400 W	15	200 W	20	300 W	40	600 W	60	900 W
1 tube with parallel compensation (2)	18 W	50		133		15	to	20	to	40	to	60	to
	20 W	45		120		15	800 W	20	1200 W	40	2400 W	60	3500 W
	36 W	25		66		15		20		40		60	
	40 W	22		60		15		20		40		60	
	58 W	16		42		10		15		30		43	
	65 W	13		37		10		15		30		43	
	80 W	11		30		10		15		30		43	
	115 W	7		20		5		7		14		20	
	2 x 18 W	56	2000 W	148	5300 W	30	1100 W	46	1650 W	80	2900 W	123	4450 W
	4 x 18 W	28		74		16	to	24	to	44	to	68	to
2 or 4 tubes with series compensation	2 x 36 W	28		74		16	1500 W	24	2400 W	44	3800 W	68	5900 W
	2 x 58 W	17		45		10		16		27		42	
	2 x 65 W	15		40		10		16		27		42	
	2 x 80 W	12		33		9		13		22		34	
	2 x 115 W	8		23		6		10		16		25	
	2 x 58 W	13		34		12		19		38		57	
Fluorescent tubes with electronic ballast													
1 or 2 tubes	18 W	80	1450 W	212	3800 W	74	1300 W	111	2000 W	222	4000 W	333	6000 W
	36 W	40	to	106	to	38	to	58	to	117	to	176	to
	58 W	26	1550 W	69	4000 W	25	1400 W	37	2200 W	74	4400 W	111	6600 W
	2 x 18 W	40		106		36		55		111		166	
	2 x 36 W	20		53		20		30		60		90	
	2 x 58 W	13		34		12		19		38		57	

Fig. N51 : Maximum number of light fittings for each relay, according to the type, power and configuration of a given lamp (Continued on opposite page)

Type of lamp	Unit power and capacitance of power factor correction capacitor	Maximum number of light fittings for a single-phase circuit and maximum power output per circuit												
		TL impulse relay				CT contactor								
		16 A		32 A		16 A		25 A		40 A		63 A		
Compact fluorescent lamps														
With external electronic ballast	5 W	240	1200 W	630	3150 W	210	1050 W	330	1650 W	670	3350 W	not tested		
	7 W	171	to	457	to	150	to	222	to	478	to			
	9 W	138	1450 W	366	3800 W	122	1300 W	194	2000 W	383	4000 W			
	11 W	118		318		104		163		327				
	18 W	77		202		66		105		216				
	26 W	55		146		50		76		153				
With integral electronic ballast (replacement for incandescent lamps)	5 W	170	850 W	390	1950 W	160	800 W	230	1150 W	470	2350 W	710	3550 W	
	7 W	121	to	285	to	114	to	164	to	335	to	514	to	
	9 W	100	1050 W	233	2400 W	94	900 W	133	1300 W	266	2600 W	411	3950 W	
	11 W	86		200		78		109		222		340		
	18 W	55		127		48		69		138		213		
	26 W	40		92		34		50		100		151		
High-pressure mercury vapour lamps with ferromagnetic ballast without ignitor														
Replacement high-pressure sodium vapour lamps with ferromagnetic ballast with integral ignitor (3)														
Without compensation (1)	50 W		not tested, infrequent use				15	750 W	20	1000 W	34	1700 W	53	2650 W
	80 W						10	to	15	to	27	to	40	to
	125 / 110 W (3)						8	1000 W	10	1600 W	20	2800 W	28	4200 W
	250 / 220 W (3)						4		6		10		15	
	400 / 350 W (3)						2		4		6		10	
	700 W						1		2		4		6	
With parallel compensation (2)	50 W	7 µF					10	500 W	15	750 W	28	1400 W	43	2150 W
	80 W	8 µF					9	to	13	to	25	to	38	to
	125 / 110 W (3)	10 µF					9	1400 W	10	1600 W	20	3500 W	30	5000 W
	250 / 220 W (3)	18 µF					4		6		11		17	
	400 / 350 W (3)	25 µF					3		4		8		12	
	700 W	40 µF					2		2		5		7	
	1000 W	60 µF					0		1		3		5	
	Low-pressure sodium vapour lamps with ferromagnetic ballast with external ignitor													
Without compensation (1)	35 W		not tested, infrequent use				5	270 W	9	320 W	14	500 W	24	850 W
	55 W						5	to	9	to	14	to	24	to
	90 W						3	360 W	6	720 W	9	1100 W	19	1800 W
	135 W						2		4		6		10	
	180 W						2		4		6		10	
With parallel compensation (2)	35 W	20 µF	38	1350 W	102	3600 W	3	100 W	5	175 W	10	350 W	15	550 W
	55 W	20 µF	24		63		3	to	5	to	10	to	15	to
	90 W	26 µF	15		40		2	180 W	4	360 W	8	720 W	11	1100 W
	135 W	40 µF	10		26		1		2		5		7	
	180 W	45 µF	7		18		1		2		4		6	
High-pressure sodium vapour lamps														
Metal-iodide lamps														
With ferromagnetic ballast with external ignitor, without compensation (1)	35 W		not tested, infrequent use				16	600 W	24	850 W	42	1450 W	64	2250 W
	70 W						8		12	to	20	to	32	to
	150 W						4		7	1200 W	13	2000 W	18	3200 W
	250 W						2		4		8		11	
	400 W						1		3		5		8	
	1000 W						0		1		2		3	
With ferromagnetic ballast with external ignitor and parallel compensation (2)	35 W	6 µF	34	1200 W	88	3100 W	12	450 W	18	650 W	31	1100 W	50	1750 W
	70 W	12 µF	17	to	45	to	6	to	9	to	16	to	25	to
	150 W	20 µF	8	1350 W	22	3400 W	4	1000 W	6	2000 W	10	4000 W	15	6000 W
	250 W	32 µF	5		13		3		4		7		10	
	400 W	45 µF	3		8		2		3		5		7	
	1000 W	60 µF	1		3		1		2		3		5	
With electronic ballast	2000 W	85 µF	0		1		0		1		2		3	
	35 W		38	1350 W	87	3100 W	24	850 W	38	1350 W	68	2400 W	102	3600 W
	70 W		29	to	77	to	18	to	29	to	51	to	76	to
	150 W		14	2200 W	33	5000 W	9	1350 W	14	2200 W	26	4000 W	40	6000 W

(1) Circuits with non-compensated ferromagnetic ballasts consume twice as much current for a given lamp power output. This explains the small number of lamps in this configuration.

(2) The total capacitance of the power factor correction capacitors in parallel in a circuit limits the number of lamps that can be controlled by a contactor. The total downstream capacitance of a modular contactor of rating 16, 25, 40 or 63 A should not exceed 75, 100, 200 or 300 µF respectively. Allow for these limits to calculate the maximum acceptable number of lamps if the capacitance values are different from those in the table.

(3) High-pressure mercury vapour lamps without ignitor, of power 125, 250 and 400 W, are gradually being replaced by high-pressure sodium vapour lamps with integral ignitor, and respective power of 110, 220 and 350 W.

Fig. N51 : Maximum number of light fittings for each relay, according to the type, power and configuration of a given lamp (Concluded)

Protection of lamp circuits: Maximum number of lamps and MCB rating versus lamp type, unit power and MCB tripping curve

During start up of discharge lamps (with their ballast), the inrush current drawn by each lamp may be in the order of:

- 25 x circuit start current for the first 3 ms
- 7 x circuit start current for the following 2 s

For fluorescent lamps with High Frequency Electronic control ballast, the protective device ratings must cope with 25 x inrush for 250 to 350 μ s.

However due to the circuit resistance the total inrush current seen by the MCB is lower than the summation of all individual lamp inrush current if directly connected to the MCB.

The tables below (see **Fig. N52 to NXX**) take into account:

- Circuits cables have a length of 20 meters from distribution board to the first lamp and 7 meters between each additional fittings.
- MCB rating is given to protect the lamp circuit in accordance with the cable cross section, and without unwanted tripping upon lamp starting.
- MCB tripping curve (C = instantaneous trip setting 5 to 10 In, D = instantaneous trip setting 10 to 14 In).

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	MCB rating C & D tripping curve																			
14/18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
14 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
14 x3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10
14 x4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10
18 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
18 x4	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10
21/24	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
21/24 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
28	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
28 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10
35/36/39	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
35/36 x2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10
38/39 x2	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	10
40/42	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
40/42 x2	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16
49/50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
49/50 x2	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16
54/55	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10
54/55 x2	6	6	6	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16
60	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10

N38

Fig. N52 : Fluorescent tubes with electronic ballast - Vac = 230 V

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	MCB rating C & D tripping curve																			
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
11	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
13	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
14	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
15	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
16	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
17	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
20	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
21	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
23	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
25	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10

Fig. N53 : Compact fluorescent lamps - Vac = 230 V

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MCB rating C tripping curve																				
50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10
80	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16
125	6	6	6	10	10	10	10	10	10	10	10	16	16	16	16	16	16	16	20	20
250	6	10	10	16	16	16	16	16	16	20	20	25	25	25	32	32	32	32	40	40
400	6	16	20	25	25	32	32	32	32	32	32	40	40	40	50	50	50	50	63	63
1000	16	32	40	50	50	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-
MCB rating D tripping curve																				
50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10
80	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16
125	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	16	20	20
250	6	6	10	10	10	10	16	16	16	20	20	25	25	25	32	32	32	32	40	40
400	6	10	16	16	20	20	25	25	25	32	32	40	40	40	50	50	50	50	63	63
1000	10	20	25	32	40	40	50	63	63	-	-	-	-	-	-	-	-	-	-	-

Fig. N54 : High pressure mercury vapour (with ferromagnetic ballast and PF correction) - Vac = 230 V

Lamp power (W)	Number of lamps per circuit																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MCB rating C tripping curve																				
Ferromagnetic ballast																				
18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
26	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
35/36	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
55	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10
91	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16	16
131	6	6	6	10	10	10	10	10	10	10	10	10	16	16	16	16	16	16	16	20
135	6	6	6	10	10	10	10	10	10	10	10	16	16	16	16	16	16	20	20	20
180	6	6	10	10	10	10	10	10	16	16	16	16	20	20	20	20	25	25	25	25
Electronic ballast																				
36	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
55	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
66	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10
91	6	6	6	6	6	10	10	10	10	10	10	10	10	10	10	10	16	16	16	16
MCB rating D tripping curve																				
Ferromagnetic ballast																				
18	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
26	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
35/36	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
55	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10
91	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16	16
131	6	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	16	20
135	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	20	20	20
180	6	6	6	6	10	10	10	10	16	16	16	16	20	20	20	20	25	25	25	25
Electronic ballast																				
36	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
55	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
66	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10
91	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16	16

Fig. N55 : Low pressure sodium (with PF correction) - Vac = 230 V

Lamp power (W)	1	2	3	4	5	6	7	8	Number of lamps per circuit													
	9	10	11	12	13	14	15	16	17	18	19	20	MCB rating C tripping curve									
Ferromagnetic ballast																						
50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10		
70	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16		
100	6	6	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	16		
150	6	6	10	10	10	10	10	10	6	16	16	16	16	16	16	20	20	20	25	25		
250	6	10	16	16	16	20	20	20	20	20	20	25	25	25	32	32	32	32	40	40		
400	10	16	20	25	32	32	32	32	32	32	32	40	40	40	50	50	50	50	63	63		
1000	16	32	40	50	50	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-		
Electronic ballast																						
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		
50	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10		
100	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16	16	16	16		
MCB rating D tripping curve																						
Ferromagnetic ballast																						
50	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10		
70	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16		
100	6	6	6	6	6	6	6	6	10	10	10	10	10	16	16	16	16	16	16	16		
150	6	6	6	6	6	10	10	10	10	16	16	16	16	16	16	20	20	20	25	25		
250	6	6	10	10	16	16	16	16	16	20	20	25	25	25	32	32	32	32	40	40		
400	6	10	16	16	20	20	25	25	25	32	32	40	40	40	50	50	50	50	63	63		
1000	10	20	32	32	40	40	50	63	63	-	-	-	-	-	-	-	-	-	-	-		
Electronic ballast																						
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		
50	6	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10		
100	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16	16	16	16		

Fig. N56 : High pressure sodium (with PF correction) - Vac = 230 V

Lamp power (W)	1	2	3	4	5	6	7	8	Number of lamps per circuit													
	9	10	11	12	13	14	15	16	17	18	19	20	MCB rating C tripping curve									
Ferromagnetic ballast																						
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		
70	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	16	16	16		
150	6	6	10	10	10	10	10	10	10	16	16	16	16	16	16	20	20	20	25	25		
250	6	10	16	16	16	20	20	20	20	20	25	25	25	32	32	32	32	40	40	40		
400	6	16	20	25	25	32	32	32	32	32	40	40	40	50	50	50	50	63	63	63		
1000	16	32	40	50	50	50	50	63	63	63	63	63	63	63	63	63	63	63	63	63		
1800/2000	25	50	63	63	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Electronic ballast																						
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		
70	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	10		
150	6	6	6	10	10	10	10	10	10	16	16	16	16	16	16	16	16	20	20	20		
MCB rating D tripping curve																						
Ferromagnetic ballast																						
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		
70	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	16	16	16		
150	6	6	6	6	6	10	10	10	10	16	16	16	16	16	16	20	20	20	25	25		
250	6	6	10	10	16	16	16	16	16	20	20	25	25	25	32	32	32	32	40	40		
400	6	10	16	16	20	20	25	25	25	32	32	40	40	40	50	50	50	50	63	63		
1000	16	20	32	32	40	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-		
1800	16	32	40	50	63	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
2000	20	32	40	50	63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
Electronic ballast																						
35	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6		
70	6	6	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10	10	10		
150	6	6	6	6	6	6	6	10	10	10	16	16	16	16	16	16	16	20	20	20		

Fig. N57 : Metal halide (with PF correction) - Vac = 230 V

Lamp power (W)									Number of lamps per circuit											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
MCB rating C tripping curve																				
1800	16	32	40	50	50	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-
2000	16	32	40	50	50	50	50	63	63	-	-	-	-	-	-	-	-	-	-	-
MCB rating D tripping curve																				
1800	16	20	32	32	32	32	50	63	63	-	-	-	-	-	-	-	-	-	-	-
2000	16	25	32	32	32	32	50	63	-	-	-	-	-	-	-	-	-	-	-	-

Fig. N58 : Metal halide (with ferromagnetic ballast and PF correction) - Vac = 400 V

Overload of the neutral conductor

The risk

In an installation including, for example, numerous fluorescent tubes with electronic ballasts supplied between phases and neutral, a high percentage of 3rd harmonic current can cause an overload of the neutral conductor. **Figure N59** below gives an overview of typical H3 level created by lighting.

Lamp type	Typical power	Setting mode	Typical H3 level
Incandescend lamp with dimmer	100 W	Light dimmer	5 to 45 %
ELV halogen lamp	25 W	Electronic ELV transformer	5 %
Fluorescent tube	100 W	Magnetic ballast	10 %
	< 25 W	Electronic ballast	85 %
	> 25 W	+ PFC	30 %
Discharge lamp	100 W	Magnetic ballast	10 %
		Electrical ballast	30 %

Fig. N59 : Overview of typical H3 level created by lighting

The solution

Firstly, the use of a neutral conductor with a small cross-section (half) should be prohibited, as requested by Installation standard IEC 60364, section 523–5–3.

As far as overcurrent protection devices are concerned, it is necessary to provide 4-pole circuit-breakers with protected neutral (except with the TN-C system for which the PEN, a combined neutral and protection conductor, should not be cut).

This type of device can also be used for the breaking of all poles necessary to supply luminaires at the phase-to-phase voltage in the event of a fault.

A breaking device should therefore interrupt the phase and Neutral circuit simultaneously.

Leakage currents to earth

The risk

At switch-on, the earth capacitances of the electronic ballasts are responsible for residual current peaks that are likely to cause unintentional tripping of protection devices.

Two solutions

The use of Residual Current Devices providing immunity against this type of impulse current is recommended, even essential, when equipping an existing installation (see **Fig. N60**).

For a new installation, it is sensible to provide solid state or hybrid control devices (contactors and remote-control switches) that reduce these impulse currents (activation on voltage passage through zero).

Overvoltages

The risk

As illustrated in earlier sections, switching on a lighting circuit causes a transient state which is manifested by a significant overcurrent. This overcurrent is accompanied by a strong voltage fluctuation applied to the load terminals connected to the same circuit. These voltage fluctuations can be detrimental to correct operation of sensitive loads (micro-computers, temperature controllers, etc.)

The Solution

It is advisable to separate the power supply for these sensitive loads from the lighting circuit power supply.

Sensitivity of lighting devices to line voltage disturbances

Short interruptions

■ The risk

Discharge lamps require a relighting time of a few minutes after their power supply has been switched off.

■ The solution

Partial lighting with instantaneous relighting (incandescent lamps or fluorescent tubes, or "hot restrike" discharge lamps) should be provided if safety requirements so dictate. Its power supply circuit is, depending on current regulations, usually distinct from the main lighting circuit.

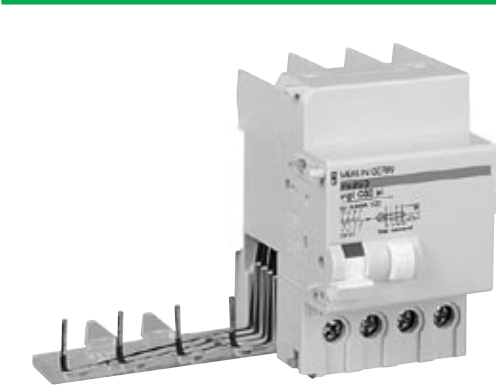


Fig. N60 : s.i. residual current devices with immunity against impulse currents (Merlin Gerin brand)

Voltage fluctuations

■ The risk

The majority of lighting devices (with the exception of lamps supplied by electronic ballasts) are sensitive to rapid fluctuations in the supply voltage. These fluctuations cause a flicker phenomenon which is unpleasant for users and may even cause significant problems. These problems depend on both the frequency of variations and their magnitude.

Standard IEC 61000-2-2 ("compatibility levels for low-frequency conducted disturbances") specifies the maximum permissible magnitude of voltage variations as a function of the number of variations per second or per minute.

These voltage fluctuations are caused mainly by high-power fluctuating loads (arc furnaces, welding machines, starting motors).

■ The solution

Special methods can be used to reduce voltage fluctuations. Nonetheless, it is advisable, wherever possible, to supply lighting circuits via a separate line supply.

The use of electronic ballasts is recommended for demanding applications (hospitals, clean rooms, inspection rooms, computer rooms, etc).

Developments in control and protection equipment

The use of light dimmers is more and more common. The constraints on ignition are therefore reduced and derating of control and protection equipment is less important. New protection devices adapted to the constraints on lighting circuits are being introduced, for example Merlin Gerin brand circuit-breakers and modular residual current circuit-breakers with special immunity, such as s.i. type ID switches and Vigi circuit-breakers. As control and protection equipment evolves, some now offer remote control, 24-hour management, lighting control, reduced consumption, etc.

4.4 Lighting of public areas**Normal lighting**

Regulations governing the minimum requirements for buildings receiving the public in most European countries are as follows:

- Installations which illuminate areas accessible to the public must be controlled and protected independently from installations providing illumination to other areas
- Loss of supply on a final lighting circuit (i.e. fuse blown or CB tripped) must not result in total loss of illumination in an area which is capable of accommodating more than 50 persons
- Protection by Residual Current Devices (RCD) must be divided amongst several devices (i.e. more than one device must be used)

Emergency lighting and other systems

When we refer to emergency lighting, we mean the auxiliary lighting that is triggered when the standard lighting fails.

Emergency lighting is subdivided as follows (EN-1838):

Safety lighting

It originates from the emergency lighting and is intended to provide lighting for people to evacuate an area safely or for those who try to finish a potentially dangerous operation before leaving the area. It is intended to illuminate the means of evacuation and ensure continuous visibility and ready usage in safety when standard or emergency lighting is needed.

Safety lighting may be further subdivided as follows:

Safety lighting for escape routes

It originates from the safety lighting, and is intended to ensure that the escape means can be clearly identified and used safely when the area is busy.

Anti-panic lighting in extended areas

It originates from the safety lighting, and is intended to avoid panic and to provide the necessary lighting to allow people to reach a possible escape route area.

Emergency lighting and safety signs for escape routes

The emergency lighting and safety signs for escape routes are very important for all those who design emergency systems. Their suitable choice helps improve safety levels and allows emergency situations to be handled better.

Standard EN 1838 ("Lighting applications. Emergency lighting") gives some fundamental concepts concerning what is meant by emergency lighting for escape routes:

"The intention behind lighting escape routes is to allow safe exit by the occupants, providing them with sufficient visibility and directions on the escape route ..."

The concept referred to above is very simple:

The safety signs and escape route lighting must be two separate things.

Functions and operation of the luminaires

The manufacturing specifications are covered by standard EN 60598-2-22, "Particular Requirements - Luminaires for Emergency Lighting", which must be read with EN 60598-1, "Luminaires – Part 1: General Requirements and Tests".

Duration

A basic requirement is to determine the duration required for the emergency lighting. Generally it is 1 hour but some countries may have different duration requirements according to statutory technical standards.

Operation

We should clarify the different types of emergency luminaires:

- Non-maintained luminaires
 - The lamp will only switch on if there is a fault in the standard lighting
 - The lamp will be powered by the battery during failure
 - The battery will be automatically recharged when the mains power supply is restored
- Maintained luminaires
 - The lamp can be switched on in continuous mode
 - A power supply unit is required with the mains, especially for powering the lamp, which can be disconnected when the area is not busy
 - The lamp will be powered by the battery during failure.

Design

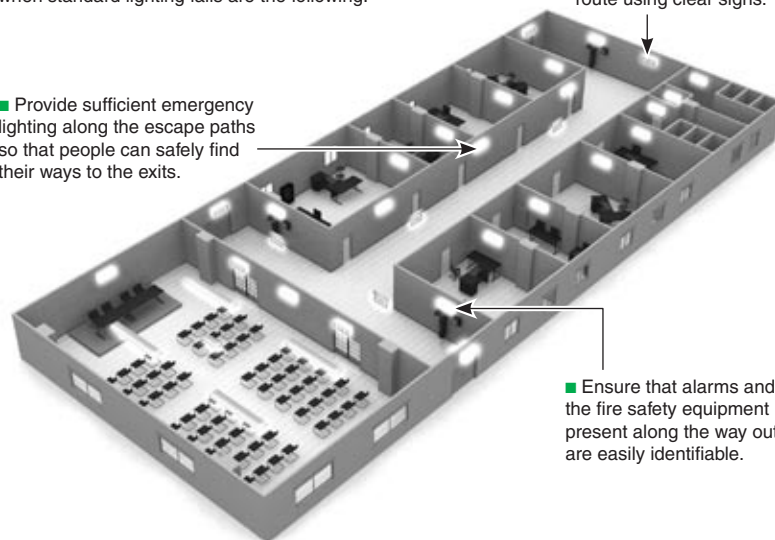
The integration of emergency lighting with standard lighting must comply strictly with electrical system standards in the design of a building or particular place.

All regulations and laws must be complied with in order to design a system which is up to standard (see **Fig. N61**).

The main functions of an emergency lighting system when standard lighting fails are the following:

- Provide sufficient emergency lighting along the escape paths so that people can safely find their ways to the exits.

- Clearly show the escape route using clear signs.



- Ensure that alarms and the fire safety equipment present along the way out are easily identifiable.

Fig. N61 : The main functions of an emergency lighting system

European standards

The design of emergency lighting systems is regulated by a number of legislative provisions that are updated and implemented from time to time by new documentation published on request by the authorities that deal with European and international technical standards and regulations.

Each country has its own laws and regulations, in addition to technical standards

which govern different sectors. Basically they describe the places that must be provided with emergency lighting as well as its technical specifications. The designer's job is to ensure that the design project complies with these standards.

EN 1838

A very important document on a European level regarding emergency lighting is the Standard EN 1838, "Lighting applications. Emergency lighting".

This standard presents specific requirements and constraints regarding the operation and the function of emergency lighting systems.

CEN and CENELEC standards

With the CEN (Comité Européen de Normalisation) and CENELEC standards (Comité Européen de Normalisation Electrotechnique), we are in a standardised environment of particular interest to the technician and the designer. A number of sections deal with emergencies. An initial distinction should be made between luminaire standards and installation standards.

EN 60598-2-22 and EN-60598-1

Emergency lighting luminaires are subject to European standard EN 60598-2-22, "Particular Requirements - Luminaires for Emergency Lighting", which is an integrative text (of specifications and analysis) of the Standard EN-60598-1, Luminaires – "Part 1: General Requirements and Tests".

The asynchronous (i.e. induction) motor is robust and reliable, and very widely used. 95% of motors installed around the world are asynchronous. The protection of these motors is consequently a matter of great importance in numerous applications.

The consequence of an incorrectly protected motor can include the following:

- For persons:
 - Asphyxiation due to the blockage of motor ventilation
 - Electrocution due to insulation failure in the motor
 - Accident due to non stopping of the motor following the failure of the control circuit in case of incorrect overcurrent protection
- For the driven machine and the process
 - Shaft couplings and axles, etc, damaged due to a stalled rotor
 - Loss of production
 - Manufacturing time delayed
- For the motor
 - Motor windings burnt out due to stalled rotor
 - Cost of dismantling and reinstalling or replacement of motor
 - Cost of repairs to the motor

Therefore, the safety of persons and goods, and reliability and availability levels are highly dependant on the choice of protective equipment.

In economic terms, the overall cost of failure must be considered. This cost is increasing with the size of the motor and with the difficulties of access and replacement. Loss of production is a further, and evidently important factor.

Specific features of motor performance influence the power supply circuits required for satisfactory operation

A motor power-supply circuit presents certain constraints not normally encountered in other (common) distribution circuits, owing to the particular characteristics, specific to motors, such as:

- High start-up current (see **Fig. N62**) which is mostly reactive, and can therefore be the cause of important voltage drop
- Number and frequency of start-up operations are generally high
- The high start-up current means that motor overload protective devices must have operating characteristics which avoid tripping during the starting period

5.1 Functions for the motor circuit

Functions generally provided are:

- Basic functions including:
 - Isolating facility
 - Motor control (local or remote)
 - Protection against short-circuits
 - Protection against overload
- Complementary protections including:
 - Thermal protection by direct winding temperature measurement
 - Thermal protection by indirect winding temperature determination
 - Permanent insulation-resistance monitoring
 - Specific motor protection functions
- Specific control equipment including:
 - Electromechanical starters
 - Control and Protective Switching devices (CPS)
 - Soft-start controllers
 - Variable speed drives

Basic functions

Isolating facility

It is necessary to isolate the circuits, partially or totally, from their power supply network for safety of personnel during maintenance work. "Isolation" function is provided by disconnectors. This function can be included in other devices designed to provide isolation such as disconnector/circuit-breaker.

Motor control

The motor control function is to make and break the motor current. In case of manual control, this function can be provided by motor-circuit-breakers or switches.

In case of remote control, this function can be provided by contactors, starters or CPS.

The control function can also be initiated by other means:

- Overload protection
- Complementary protection
- Under voltage release (needed for a lot of machines)

The control function can also be provided by specific control equipment.

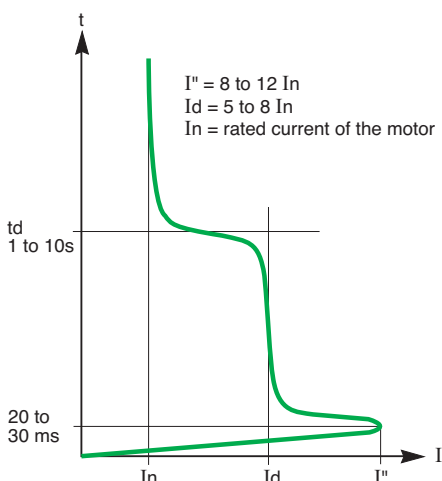


Fig. N62 : Direct on-line starting current characteristics of an induction motor

Protection against short-circuits

■ Phase-to-phase short-circuit

This type of fault inside the machine is very rare. It is generally due to mechanical incident of the power supply cable of the motor.

■ Phase-to-earth short-circuit

The deterioration of winding insulation is the main cause. The resulting fault current depends on the system of earthing. For the TN system, the resulting fault current is very high and in most cases the motor will be deteriorated. For the other systems of earthing, protection of the motor can be achieved by earth fault protection.

For short-circuit protection, it is recommended to pay special attention to avoid unexpected tripping during the starting period of the motor. The inrush current of a standard motor is about 6 to 8 times its rated current but during a fault the current can be as high as 15 times the rated current. So, the starting current must not be seen as a fault by the protection. In addition, a fault occurring in a motor circuit must not disturb any upstream circuit. As a consequence, discrimination/selectivity of magnetic protections must be respected with all parts of the installation.

Protection against overload

Mechanical overloads due to the driven machine are the main origins of the overload for a motor application. They cause overload current and motor overheating. The life of the motor can be reduced and sometimes, the motor can be deteriorated. So, it is necessary to detect motor overload. This protection can be provided by:

■ Specific thermal overload relay

■ Specific thermal-magnetic circuit-breaker commonly referred to as "motor circuit-breaker"

■ Complementary protection (see below) like thermal sensor or electronic multifunction relay

■ Electronic soft start controllers or variable speed drives (see below)

Complementary protections

■ Thermal protection by direct winding temperature measurement

Provided by thermal sensors incorporated inside the windings of the motor and associated relays.

■ Thermal protection by indirect winding temperature determination

Provided by multifunction relays through current measurement and taking into account the characteristics of the motors (e.g.: thermal time constant).

■ Permanent insulation-resistance monitoring relays or residual current differential relays

They provide detection and protection against earth leakage current and short-circuit to earth, allowing maintenance operation before destruction of the motor.

■ Specific motor protection functions

Such as protection against too long starting period or stalled rotor, protection against unbalanced, loss or permutation of phases, earth fault protection, no load protection, rotor blocked (during start or after)...; pre alarm overheating indication, communication, can also be provided by multifunction relays.

Specific control equipment

■ Electromechanical starters (star-delta, auto-transformer, rheostatic rotor starters,...)

They are generally used for application with no load during the starting period (pump, fan, small centrifuge, machine-tool, etc.)

□ Advantages

Good torque/current ratio; great reduction of inrush current.

□ Disadvantages

Low torque during the starting period; no easy adjustment; power cut off during the transition and transient phenomenon; 6 motor connection cables needed.

■ Control and Protective Switching devices (CPS)

They provide all the basic functions listed before within a single unit and also some complementary functions and the possibility of communication. These devices also provide continuity of service in case of short-circuit.

■ Soft-start controllers

Used for applications with pump, fan, compressor, conveyor.

□ Advantages

Reduced inrush current, voltage drop and mechanical stress during the motor start; built-in thermal protection; small size device; possibility of communication

□ Disadvantages

Low torque during the starting period; thermal dissipation.

■ Variable speed drives

They are used for applications with pump, fan, compressor, conveyor, machine with high load torque, machine with high inertia.

□ Advantages

Continuous speed variation (adjustment typically from 2 to 130% of nominal speed), overspeed is possible; accurate control of acceleration and deceleration; high torque during the starting and stopping periods; low inrush current, built-in thermal protection, possibility of communication.

□ Disadvantages

Thermal dissipation, volume, cost.

5.2 Standards

The motor control and protection can be achieved in different way:

■ By using an association of a SCPD (Short-Circuit-Protective-Device) and electromechanical devices such as

□ An electromechanical starters fulfilling the standard IEC 60947-4-1

□ A semiconductor starter fulfilling the standard IEC 60947-4-2

□ A variable speed drives fulfilling the standard series IEC 61800

■ By using a CPS, single device covering all the basic functions, and fulfilling the standard IEC 60947-6-2

In this document, only the motor circuits including association of electromechanical devices such as, starters and protection against short-circuit, are considered. The devices meeting the standard 60947-6-2, the semiconductor starters and the variable speed drives will be considered only for specific points.

A motor circuit will meet the rules of the IEC 60947-4-1 and mainly:

■ The co-ordination between the devices of the motor circuit

■ The tripping class of the thermal relays

■ The category of utilization of the contactors

■ The insulation co-ordination

Note: The first and last points are satisfied inherently by the devices meeting the IEC 60947-6-2 because they provide a continuity of service.

Standardization of the association circuit-breaker + contactor + thermal relay

Control devices categories

The standards in the IEC 60947 series define the utilisation categories according to the purposes the control gear is designed for (see **Fig. N63**). Each category is characterised by one or more operating conditions such as:

■ Currents

■ Voltages

■ Power factor or time constant

■ And if necessary, other operating conditions

N47

Type of current	Operating categories	Typical uses
Alternating current	AC-1	Non inductive or slightly inductive load, resistance furnace. Power distribution (lighting, generators, etc.).
	AC-2	Brush motor: starting, breaking. Heavy duty equipment (hoisting, handling, crusher, rolling-mill train, etc.).
	AC-3	Squirrel cage motor: starting, switching off running motors. Motor control (pumps, compressors, fans, machine-tools, conveyors, presses, etc.).
	AC-4	Squirrel cage motor: starting, plugging, inching. Heavy-duty equipment (hoisting, handling, crusher, rolling-mill train, etc.).
Direct current	DC-1	Non inductive or slightly inductive load, resistance furnace.
	DC-3	Shunt wound motor: starting, reversing, counter-current breaking, inching. Dynamic breaking for direct current motors.
	DC-5	Series wound motor: starting, reversing, counter-current breaking, inching. Dynamic breaking for direct current motors.

* Category AC-3 can be used for the inching or reversing, counter-current breaking for occasional operations of a limited length of time, such as for the assembly of a machine. The number of operations per limited length of time normally do not exceed five per minute and ten per 10 minutes.

Fig. N63 : Contactor utilisation categories based on the purposes they are designed for, according to IEC 60947-1

The following is also taken into consideration:

- Circuit making and breaking conditions
- Type of load (squirrel cage motor, brush motor, resistor)
- Conditions in which making and breaking take place (motor running, motor stalled, starting process, counter-current breaking, etc.)

Coordination between protections and control

It is coordination, the most efficient combination of the different protections (against short circuits and overloads) and the control device (contactor) which make up a motor starter unit.

Studied for a given power, it provides the best possible protection of the equipment controlled by this motor starter unit (see **Fig. N64**).

It has the double advantage of reducing equipment and maintenance costs as the different protections complement each other as exactly as possible, with no useless redundancy.

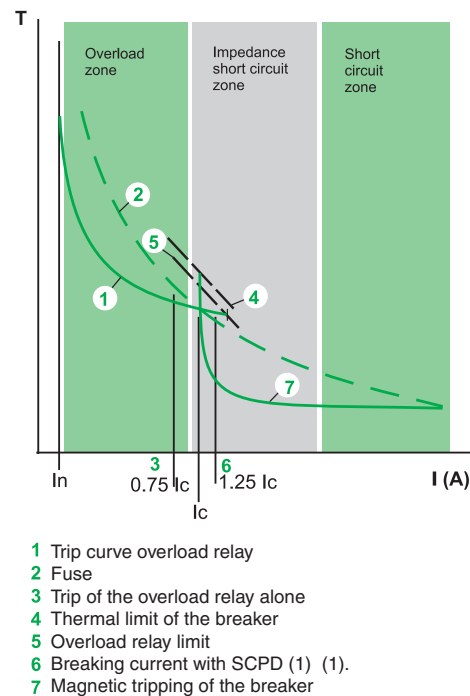


Fig. N64 : The basics of coordination

There are different types of coordination

Two types of coordination (type 1 and type 2) are defined by IEC 60947-4-1.

■ Type 1 coordination:

The commonest standard solution. It requires that in event of a short circuit, the contactor or the starter do not put people or installations in danger. It admits the necessity of repairs or part replacements before service restoration.

■ Type 2 coordination:

The high performance solution. It requires that in the event of a short circuit, the contactor or the starter do not put people or installations in danger and that it is able to work afterwards. It admits the risk of contact welding. In this case, the manufacturer must specify the measures to take for equipment maintenance.

■ Some manufacturers offer:

The highest performance solution, which is “**Total coordination**”.

This coordination requires that in the event of a short circuit, the contactor or the starter do not put people or installations in danger and that it is able to work afterwards. It does not admit the risk of contact welding and the starting of the motor starter unit must be immediate.

Control and protection switching gear (CPS)

CPS or “starter-controllers” are designed to fulfil control and protection functions simultaneously (overload and short circuit). In addition, they are designed to carry out control operations in the event of a short circuit.

They can also assure additional functions such as insulation, thereby totally fulfilling the function of “motor starter unit”. They comply with standard IEC 60947-6-2, which notably defines the assigned values and utilisation categories of a CPS, as do standards IEC 60947-1 and 60947-4-1.

The functions performed by a CPS are combined and coordinated in such a way as to allow for uptime at all currents up to the lcs working short circuit breaking capacity of the CPS. The CPS may or may not consist of one device, but its characteristics are assigned as for a single device. Furthermore, the guarantee of “total” coordination of all the functions ensures the user has a simple choice with optimal protection which is easy to implement.

Although presented as a single unit, a CPS can offer identical or greater modularity than the “three product” motor starter unit solution. This is the case with the “Tesys U” starter-controller (see **Fig. N65**).

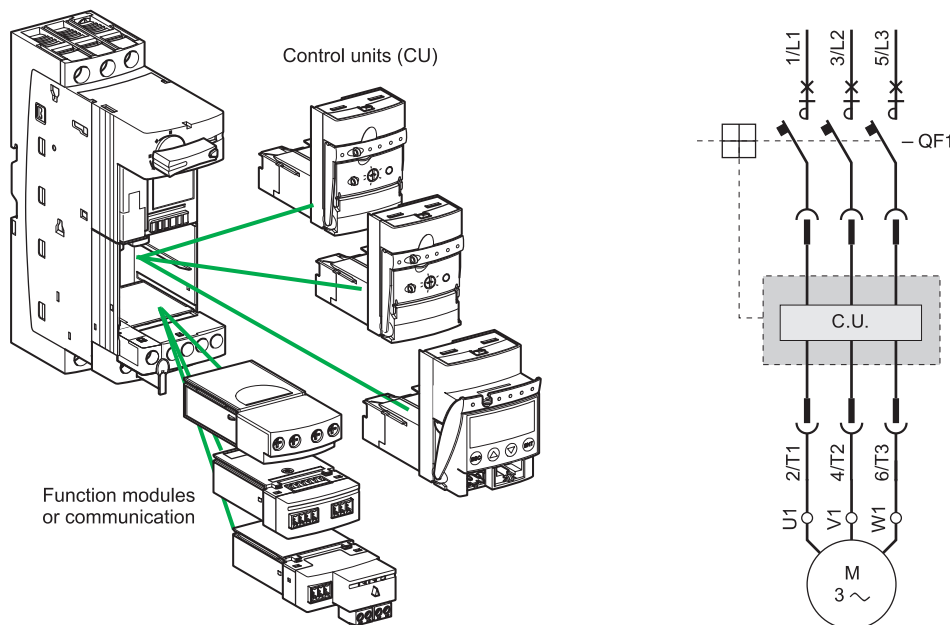


Fig. N65 : Example of a CPS modularity (Tesys Ustarter controller by Telemecanique)

This starter-controller can at any time bring in or change a control unit with protection and control functions for motors from 0.15A to 32A in a generic “base power” or “base unit” of a 32 A calibre.

Additional functionality's can also be installed with regard to:

- Power, reversing block, limiter
- Control
- Functions modules, alarms, motor load, automatic resetting, etc,
- Communication modules: AS-I, Modbus, Profibus, CAN-Open, etc,
- Auxiliary contact modules, added contacts.

Communications functions are possible with this system (see **Fig. N66**).

Available functions:	Standard	Control units: Upgradeable	Multifunction
Starter status (ready, running, with default)			
Alarms (overcurrents...)			
Thermal alarm			
Remote resetting by bus			
Indication of motor load			
Defaults differentiation			
Parameter setting and protection function reference			
"Log file" function			
"Monitoring" function			
Start and Stop controls			

Information conveyed by bus (Modbus) and functions performed

Fig. N66 : Tesys U Communication functions

What sort of coordination does one choose?

The choice of the coordination type depends on the operation parameters. It should be made to achieve the best balance of user needs and installation costs.

■ Type 1

Acceptable when uptime is not required and the system can be reactivated after replacing the faulty parts.

In this case the maintenance service must be efficient (available and competent). The advantage is reduced equipment costs.

■ Type 2

To be considered when the uptime is required.

It requires a reduced maintenance service.

When immediate motor starting is necessary, "Total coordination" must be retained.

No maintenance service is necessary.

The coordinations offered in the manufacturers' catalogues simplify the users' choice and guarantees that the motor starter unit complies with the standard.

5.3 Applications

The control and protection of a motor can consist of one, two, three or four different devices which provide one or several functions.

In the case of the combination of several devices, co-ordination between them is essential in order to provide optimized protection of the motor application.

To protect a motor circuit, many parameters must be taken into account. They depend on:

- The application (type of driven machine, safety of operation, number of operations, etc.)
- The continuity performance requested by the application
- The standards to be enforced to provide security and safety.

The electrical functions to be provided are quite different:

- Start, normal operation and stop without unexpected tripping while maintaining control requirements, number of operations, durability and safety requirements (emergency stops), as well as circuit and motor protection, disconnection (isolation) for safety of personnel during maintenance work.

Among the many possible methods of protecting a motor, the association of a circuit breaker + contactor + thermal relay⁽¹⁾ provides many advantages

Basic protection schemes: circuit-breaker + contactor + thermal relay

Advantages

The combination of devices facilitates installation work, as well as operation and maintenance, by:

- The reduction of the maintenance work load: the circuit-breaker avoids the need to replace blown fuses and the necessity of maintaining a stock (of different sizes and types)
- Better continuity performance: the installation can be re-energized immediately following the elimination of a fault and after checking of the starter
- Additional complementary devices sometimes required on a motor circuit are easily accommodated
- Tripping of all three phases is assured (thereby avoiding the possibility of "single phasing")
- Full load current switching possibility (by circuit-breaker) in the event of contactor failure, e.g. contact welding
- Interlocking
- Diverse remote indications
- Better protection for the starter in case of overcurrent and in particular for impedant short-circuit⁽²⁾ corresponding to currents up to about 30 times I_n of motor (see Fig. N67).
- Possibility of adding RCD:
 - Prevention of risk of fire (sensitivity 500 mA)
 - Protection against destruction of the motor (short-circuit of laminations) by the early detection of earth fault currents (sensitivity 300 mA to 30 A)

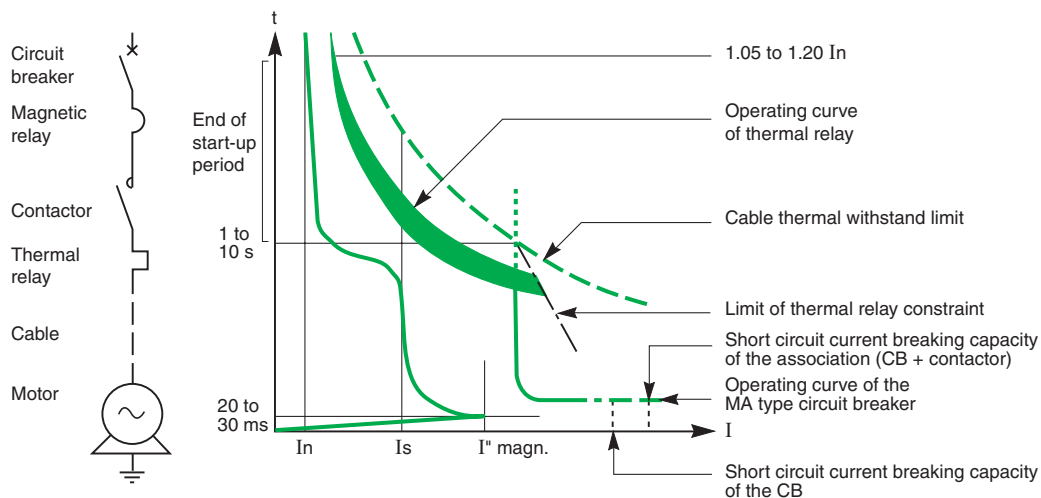


Fig. N67 : Tripping characteristics of a circuit-breaker + contactor + thermal relay⁽¹⁾

Conclusion

The combination of a circuit-breaker + contactor + thermal relay for the control and protection of motor circuits is eminently appropriate when:

- The maintenance service for an installation is reduced, which is generally the case in tertiary and small and medium sized industrial sites
- The job specification calls for complementary functions
- There is an operational requirement for a load breaking facility in the event of need of maintenance.

(1) The combination of a contactor with a thermal relay is commonly referred to as a "discontactor".

(2) In the majority of cases, short-circuit faults occur at the motor, so that the current is limited by the cable and the wiring of the starter and are called impedant short-circuits

Key points in the successful combination of a circuit-breaker and a disconnector

Standards define precisely the elements which must be taken into account to achieve a correct coordination of type 2:

- Absolute compatibility between the thermal relay of the disconnector and the magnetic trip of the circuit-breaker. In **Figure N68** the thermal relay is protected if its limit boundary for thermal withstand is placed to the right of the circuit-breaker magnetic trip characteristic curve. In the case of a motor control circuit-breaker incorporating both magnetic and thermal relay devices, coordination is provided by design.
- The overcurrent breaking capability of the contactor must be greater than the current corresponding to the setting of the circuit-breaker magnetic trip relay.
- When submitted to a short-circuit current, the contactor and its thermal relay must perform in accordance with the requirements corresponding to the specified type of co-ordination.

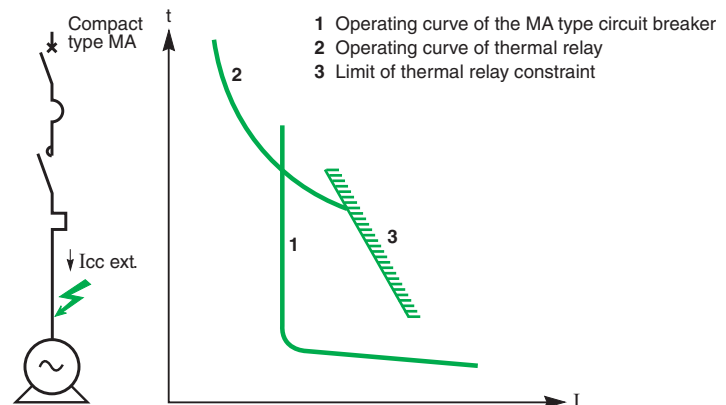


Fig. N68 : The thermal-withstand limit of the thermal relay must be to the right of the CB magnetic-trip characteristic

It is not possible to predict the short-circuit current-breaking capacity of a circuit-breaker + contactor combination. Only laboratory tests by manufacturers allow to do it. So, Schneider Electric can give table with combination of Multi 9 and Compact type MA circuit-breakers with different types of starters

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Short-circuit current-breaking capacity of a circuit-breaker + contactor combination

At the selection stage, the short-circuit current-breaking capacity which must be compared to the prospective short-circuit current is:

- Either, that of the circuit-breaker + contactor combination if the circuit-breaker and the contactor are physically close together (see **Fig. N69**) (same drawer or compartment of a motor control cabinet). A short-circuit downstream of the combination will be limited to some extent by the impedances of the contactor and the thermal relay. The combination can therefore be used on a circuit for which the prospective short-circuit current level exceeds the rated short-circuit current-breaking capacity of the circuit-breaker. This feature very often presents a significant economic advantage
- Or that of the circuit-breaker only, for the case where the contactor is separated (see **Fig. N70**) with the risk of short-circuit between the contactor and the circuit-breaker.

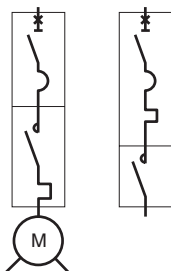


Fig. N69 : Circuit-breaker and contactor mounted side by side

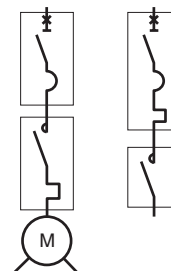


Fig. N70 : Circuit-breaker and contactor mounted separately

Choice of instantaneous magnetic-trip relay for the circuit-breaker

The operating threshold must never be less than 12 In for this relay, in order to avoid unexpected tripping due to the first current peak during motor starting.

Complementary protections

Complementary protections are:

- Thermal sensors in the motor (windings, bearings, cooling-air ducts, etc.)
- Multifunction protections (association of functions)
- Insulation-failure detection devices on running or stationary motor

Thermal sensors

Thermal sensors are used to detect abnormal temperature rise in the motor by direct measurement. The thermal sensors are generally embedded in the stator windings (for LV motors), the signal being processed by an associated control device acting to trip the contactor or the circuit-breaker (see **Fig. N71**).

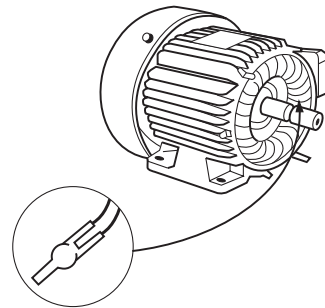


Fig. N71 : Overheating protection by thermal sensors

Multifunction motor protection relay

The multifunction relay, associated with a number of sensors and indication modules, provides protection for motor and also for some functions, protection of the driven machine such as:

- Thermal overload
- Stalled rotor, or starting period too long
- Overheating
- Unbalanced phase current, loss of one phase, inverse rotation
- Earth fault (by RCD)
- Running at no-load, blocked rotor on starting

The advantages are essentially:

- A comprehensive protection, providing a reliable, high performance and permanent monitoring/control function
- Efficient monitoring of all motor-operating schedules
- Alarm and control indications
- Possibility of communication via communication buses

Example: Telemecanique LT6 relay with permanent monitoring/control function and communication by bus, or multifunction control unit LUCM and communication module for TeSys model U.

Preventive protection of stationary motors

This protection concerns the monitoring of the insulation resistance level of a stationary motor, thereby avoiding the undesirable consequences of insulation failure during operation such as:

- Failure to start or to perform correctly for motor used on emergency systems
- Loss of production

This type of protection is essential for emergency systems motors, especially when installed in humid and/or dusty locations. Such protection avoids the destruction of a motor by short-circuit to earth during starting (one of the most frequently-occurring incidents) by giving a warning informing that maintenance work is necessary to restore the motor to a satisfactory operational condition.

Example of application:

Motors driving pumps for “sprinklers” fire-protection systems or irrigation pumps for seasonal operation.

A VigiloHM SN21 (Merlin Gerin) monitors the insulation of a motor, and signals audibly and visually any abnormal reduction of the insulation resistance level. Furthermore, this relay can prevent any attempt to start the motor, if necessary (see **Fig. N72**).

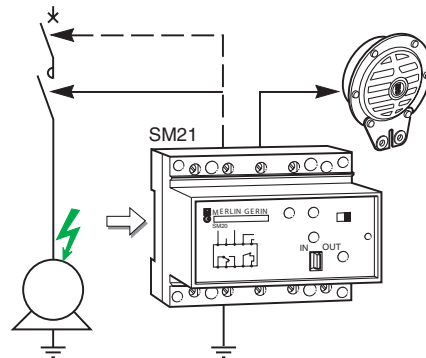


Fig. N72 : Preventive protection of stationary motors

Limitative protections

Residual current differential protective devices (RCDs) can be very sensitive and detect low values of leakage current which occur when the insulation to earth of an installation deteriorates (by physical damage, contamination, excessive humidity, and so on). Some versions of RCDs, with dry contacts, specially designed for such applications, provide the following:

- To avoid the destruction of a motor (by perforation and short-circuiting of the laminations of the stator) caused by an eventual arcing fault to earth. This protection can detect incipient fault conditions by operating at leakage currents in the range of 300 mA to 30 A, according to the size of the motor (approx sensitivity: 5% I_n)
- To reduce the risk of fire: sensitivity ≤ 500 mA

For example, RH99M relay (Merlin Gerin) provides (see **Fig. N73**):

- 5 sensitivities (0.3; 1; 3; 10; 30 A)
- Possibility of discrimination or to take account of particular operation by virtue of 3 possible time delays (0, 90, 250 ms)
- Automatic breaking if the circuit from the current transformer to the relay is broken
- Protection against unwanted trippings
- Protection against DC leakage currents (type A RCD)

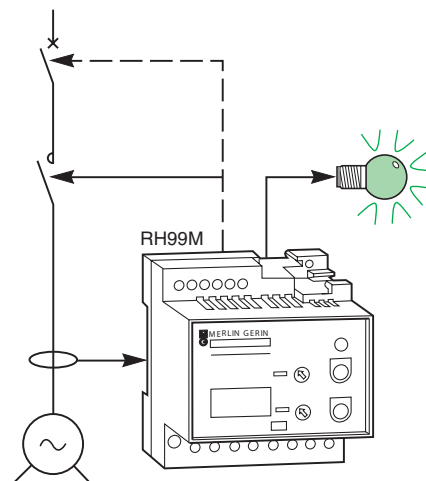


Fig. N73 : Example using relay RH99M

The importance of limiting the voltage drop at the motor terminals during start-up

In order to have a motor starting and accelerating to its normal speed in the appropriate time, the torque of the motor must exceed the load torque by at least 70%. However, the starting current is much higher than the full-load current of the motor. As a result, if the voltage drop is very high, the motor torque will be excessively reduced (motor torque is proportional to U^2) and it will result, for extreme case, in failure to start.

Example:

■ With 400 V maintained at the terminals of a motor, its torque would be 2.1 times that of the load torque

■ For a voltage drop of 10% during start-up, the motor torque would be $2.1 \times 0.9^2 = 1.7$ times the load torque, and the motor would accelerate to its rated speed normally

■ For a voltage drop of 15% during start-up, the motor torque would be $2.1 \times 0.85^2 = 1.5$ times the load torque, so that the motor starting time would be longer than normal

In general, a maximum allowable voltage drop of 10% is recommended during start-up of the motor.

5.4 Maximum rating of motors installed for consumers supplied at LV

The disturbances caused on LV distribution networks during the start-up of large direct-on-line AC motors can cause considerable nuisance to neighbouring consumers, so that most power-supply utilities have strict rules intended to limit such disturbances to tolerable levels. The amount of disturbance created by a given motor depends on the “strength” of the network, i.e. on the short-circuit fault level at the point concerned. The higher the fault level, the “stronger” the system and the lower the disturbance (principally voltage drop) experienced by neighbouring consumers. For distribution networks in many countries, typical values of maximum allowable starting currents and corresponding maximum power ratings for direct-on-line motors are shown in **Figures N74** and **N75** below.

Type of motor	Location	Maximum starting current (A)	
		Overhead-line network	Underground-cable network
Single phase	Dwellings	45	45
	Others	100	200
Three phase	Dwellings	60	60
	Others	125	250

Fig. N74 : Maximum permitted values of starting current for direct-on-line LV motors (230/400 V)

Location	Type of motor		
	Single phase 230 V (kW)	Three phase 400 V Direct-on-line starting at full load (kW)	Other methods of starting (kW)
Dwellings	1.4	5.5	11
Others	Overhead line network	11	22
	Underground cable network	22	45

Fig. N75 : Maximum permitted power ratings for LV direct-on-line starting motors

Since, even in areas supplied by one power utility only, “weak” areas of the network exist as well as “strong” areas, it is always advisable to secure the agreement of the power supplier before acquiring the motors for a new project.

Other (but generally more costly) alternative starting arrangements exist, which reduce the large starting currents of direct-on-line motors to acceptable levels; for example, star-delta starters, slip-ring motor, “soft start” electronic devices, etc.

5.5 Reactive-energy compensation (power-factor correction)

The method to correct the power factor is indicated in chapter L.